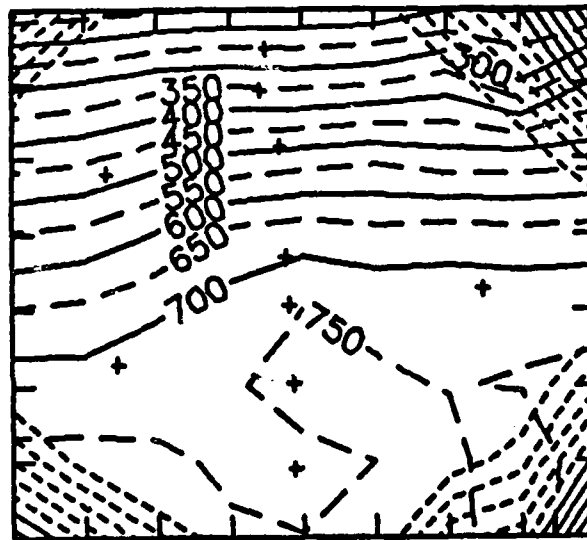


THE SYNOP PILOT EXPERIMENT:

Inverted Echo Sounder Data Report
for
November 1986 to March 1987

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Abstract

The SYNOP Pilot Experiment was conducted off Cape Hatteras, from late November 1986 to early March 1987, to measure the path characteristics (position, angle, curvature), the time-varying current structure and transport of the Gulf Stream. Part of the purpose of this Experiment was to test new instrumentation techniques and moored array designs for a subsequent main SYNOP Experiment. Data collected as part of the Pilot Experiment included Inverted Echo Sounders (IESs), Current Meter moorings (CMs) and Acoustic Transport Meters (ATMs). This report documents the IES data and ATM data collected during the deployment period. Time series plots of the travel time and low-pass filtered thermocline depth measurements are presented for eleven instruments. Bottom pressure and temperature, measured at three of the sites, are also plotted. Basic statistics are given for all the data records shown. Maps of the thermocline depth field in a 160 Km by 140 Km region are presented at daily intervals.

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Contents

Abstract	iii
List of Tables	vii
List of Figures	viii
1 EXPERIMENT DESCRIPTION AND DATA PROCESSING	1
1.1 Introduction	1
1.2 Site Naming Conventions	2
1.3 Inverted Echo Sounder Description	4
1.4 Data Processing	5
1.4.1 Travel Time Calibration	7
1.4.2 Thermocline Depth Mapping	8
1.4.3 Temperature	9
1.4.4 Bottom pressure	10
1.4.5 Time Base	11
1.5 Acoustic Ocean-Transport Meter Description	11
1.6 Data Recovery	14
2 INDIVIDUAL SITE AND RECORD INFORMATION TABLES	15
3 HALF-HOURLY DATA FOR EACH CROSS-STREAM LINE	32
3.1 Travel Time Data	33
3.2 Bottom Pressure Data	35
3.3 Temperature Data	37
4 40 HRLP DATA FOR EACH CROSS-STREAM LINE	38
4.1 Thermocline Depth Data	39
4.2 Bottom Pressure Data	41
4.3 Temperature Data	42
5 THERMOCLINE DEPTH MAPS	43
5.1 Mean and Variance Fields	44
5.2 Error Fields	45

List of Figures

1	The SYNOP Pilot Experiment field observations area	3
2	IES data processing flowchart	6
3.1	Half-hourly travel time records from IES87A1 and IES87A2 along Line A, and IES87C1 and IES87C2 along Line C	33
3.2	Half-hourly travel time records from PIES87B1, PIES87B3, IES87B5, PIES87B6 and IES87B7, and six-hourly from ATM87B2 and ATM87B4 along Line B . .	34
4	Half-hourly measured bottom pressure records for PIES87B1, PIES87B3, and PIES87B6	35
5	Half-hourly residual bottom pressure records for PIES87B1 and PIES87B3 .	36
6	Half-hourly temperature records for PIES87B1, PIES87B3 and PIES87B6 .	37
7.1	Thermocline depth records for Line A and Line C	39
7.2	Thermocline depth records for Line B	40
8	40HRLP bottom pressure records for PIES87B1 and PIES87B3	41
9	40HRLP temperature records for PIES87B1, PIES87B3 and PIES87B6 . . .	42
10	Mean and variance fields	44
11	Error (percent variance) and error-bar fields	45
12	Daily thermocline depth maps	46

5.3 Daily Thermocline Depth Maps	46
Acknowledgments	58
References	59

List of Tables

1	Instruments Location and Data Returns	4
2	Yearhour Calendar for Non-leap years	12
3	IES87A1	16
4	IES87A2	17
5	PIES87B1	18
6	ATM87B2	21
7	PIES87B3	22
8	ATM87B4	25
9	IES87B5	26
10	PIES87B6	27
11	IES87B7	29
12	IES87C1	30
13	IES87C2	31

1 Experiment Description and Data processing

1.1 Introduction

This report documents data collected using Inverted Echo Sounders (IESs) in the Gulf Stream off Cape Hatteras from November 1986 to March 1987. The measurements were made under the support of an ONR project entitled "SYNOP Pilot Experiment." Other data collected as part of this Pilot Experiment included (a) two Current Meter moorings (CMs) with five levels of each mooring, at depths of 400, 700, 1000 and 2000 m and 50 m above the bottom (Co-P.I., J. Bane, University of North Carolina), (b) tests of two acoustic doppler current profilers at the top of these moorings (W. Johns, University of Miami), (c) tests of two Acoustic Transport Meters (ATMs) (D.R. Watts, University of Rhode Island), (d) Pegasus surveys of velocity and temperature sections (K. Leaman, University of Miami), (e) tests of a new electromagnetic towed transport meter (T. Sanford, University of Washington, APL), and (f) Pop-up-profiler (A. Bradley, WHOI). The ATM data are included in this report. The other data will be documented separately.

The principal objectives of the IES and ATM portion of this SYNOP Pilot Experiment are as follows:

1. developing improved techniques for monitoring inflow conditions of the Gulf Stream as it leaves Cape Hatteras, and
2. mapping the thermocline topography by objective analysis in the region surrounding the current meter and Pegasus surveys.

The specific inflow conditions that we wish to monitor are

- path characteristics (position, angle, curvature)
- detailed cross-stream structure of the thermocline
- baroclinic and barotropic transport
- stream function and vorticity.

To contribute to our planned dynamical and statistical studies later in the SYNoptic Ocean Prediction program (SYNOP), these inlet parameters are seen as a generalization

and improvement of earlier work for the purpose of specifying "inlet conditions" for numerical prediction of the synoptic variability of the Gulf Stream farther downstream.

To address these objectives, an array of IESs, CMs and ATMs were deployed within the Gulf Stream near 35°N 74°W. In this region, there is a minimum in the lateral meander motion, as determined from several years of satellite observations of the Gulf Stream's surface temperature front.

The nine IESs and two ATMs (and two CMs) were deployed on a cruise aboard the R/V ENDEAVOR (EN152) from 20 November to 3 December 1986, and recovered on the R/V ENDEAVOR (EN156) from 26 February to 6 March 1987. During this three-month-period, the instruments were located on three sections in an rectangular grid 160 Km downstream by 140 Km cross-stream. The IES sites, designated by the solid circles in Figure 1, are spaced 35 Km cross-stream and 50 Km alongstream. Acoustic transport meters and current meter moorings are located at the sites shown by the two solid triangles. These are situated halfway between adjacent IESs, thereby giving a 35 Km spacing between them as well. Additionally, bottom pressure gauges and bottom temperature sensors are included at three IES sites located along line B (indicated by the solid box). All IES and ATM sites are listed in Table 1.

1.2 Site Naming Conventions

The three cross-stream sections are designated from west to east by the letters A through C. The IES sites along line A and line C are numbered from 1 through 2, and line B consecutively from 1 through 7, with site 1 located at the northwestern end of the section. In this report, each instrument site is referred to by both the section letter and site number, prefaced by either IES, if it is a standard instrument, or PIES, if it is a combined IES and bottom pressure gauge. For example, IES87B5 is the fifth site from the northern end of line B. Additionally, the preface ATM indicates an acoustic transport meter site.

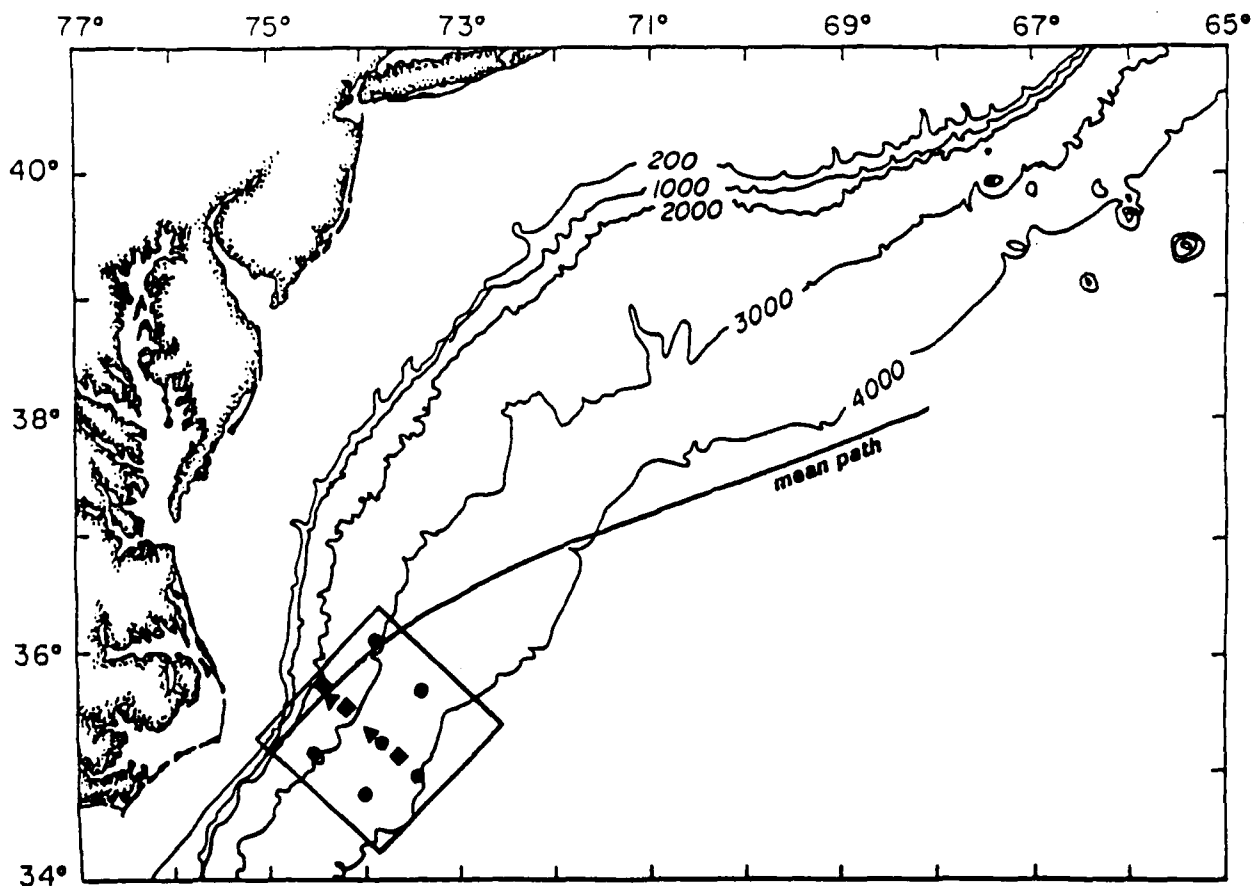


Figure 1: The SYNOP Pilot Experiment field observations area.

All IES (circles) and ATM (triangles) sites were occupied from November 1986 through February 1987. PIESs with bottom pressure gauges and temperature sensors are located at the solid rectangular boxes. The box is the 160 Km by 140 Km region, which is shown in Figure 12. The solid line through the area shows the historical mean path of the Gulf Stream.

Table 1: Site Location and Data Returns

SITE	LATITUDE(N)	LONGITUDE(W)	DEPLOYMENT PERIOD (DATES)
			1986 — 1987
IES87A1	35°16.12	74°32.94	Nov 28 – Mar 2
IES87A2	34°58.08	74°07.89	Nov 27 – Mar 2
PIES87B1	35°45.64	74°27.93	Nov 25 – Feb 28
ATM87B2	35°40.67	74°23.52	Nov 30 – Feb 28
PIES87B3	35°37.07	74°13.92	Nov 26 – Mar 1
ATM87B4	35°26.50	73°59.47	Nov 24 – Feb 28
IES87B5	35°22.06	73°53.06	Nov 26 – Feb 28
PIES87B6	35°14.54	73°42.92	Nov 27 – Feb 28
IES87B7	35°06.05	73°31.94	Nov 27 – Mar 1
IES87C1	36°02.80	73°52.90	Nov 23 – Mar 3
IES87C2	35°43.98	73°29.98	Nov 27 – Mar 3

1.3 Inverted Echo Sounder Description

A detailed description of the IES is presented in Chaplin and Watts (1984) and will not be repeated here. Briefly, however, the IES is an instrument which is moored one meter above the ocean floor and which monitors the depth of the main thermocline acoustically. A sample burst of acoustic pulses is transmitted every half hour and round trip travel times to the surface and back are recorded on a digital cassette tape within the instrument. For the standard IES, a sample burst typically consists of twenty 10 KHz pings. Additionally, bottom pressure and temperature can be measured and recorded. For instruments with these optional sensors, the travel time burst consists of 24 pings, whereas the pressure and temperature are average measurements over the whole sampling interval.

1.4 Data Processing

Most of the earlier processing was done on a PRIME 750 computer, except for the initial dumping of the data from the cassette tapes onto a 9-track magnetic tape. This was done on the Hewlett Packard 2000 series computer maintained by the URI Marine Technicians. At the last major step, objective mapping, the processing was done on our Micro Vax II computer system. The basic processing steps, which include transcription, editing, and conversion into scientific units, are illustrated by the flowchart in Figure 2. The data processing is accomplished by a series of routines specifically developed for the IES. Since these programs are documented elsewhere (Tracey and Watts, 1988), the steps are only outlined below.

RAW DATA CASSETTES : Recorded within the instruments. Contain the counts associated with travel time, pressure, and temperature measurements as a series of integer words of varying lengths.

CARP : Transfers the data from cassettes to 9-track magnetic tape for subsequent processing.

BUNS : Converts the series of integer words of varying lengths into standard length 32-bit integer words.

PUNS : Produces integer listings and histograms of the travel time sample bursts. Provides an initial look at data quality and travel time distributions. Used to determine the first (after launch) and last (before recovery) 'on bottom' samples.

MEMOD : Establishes the time base. Determines either the median or modal value (at the user's option) of the travel time burst as the representative measurement. Converts all travel time, pressure and temperature counts into specific units of seconds, decibars, and degrees Celsius, respectively.

FILL : Checks for proper incrementing of the time base. Missing data points are filled by inserting interpolated values.

DETIDE : From user-supplied tidal constituents specific to each site, determines the tidal contribution to the travel times and removes it from the measured values.

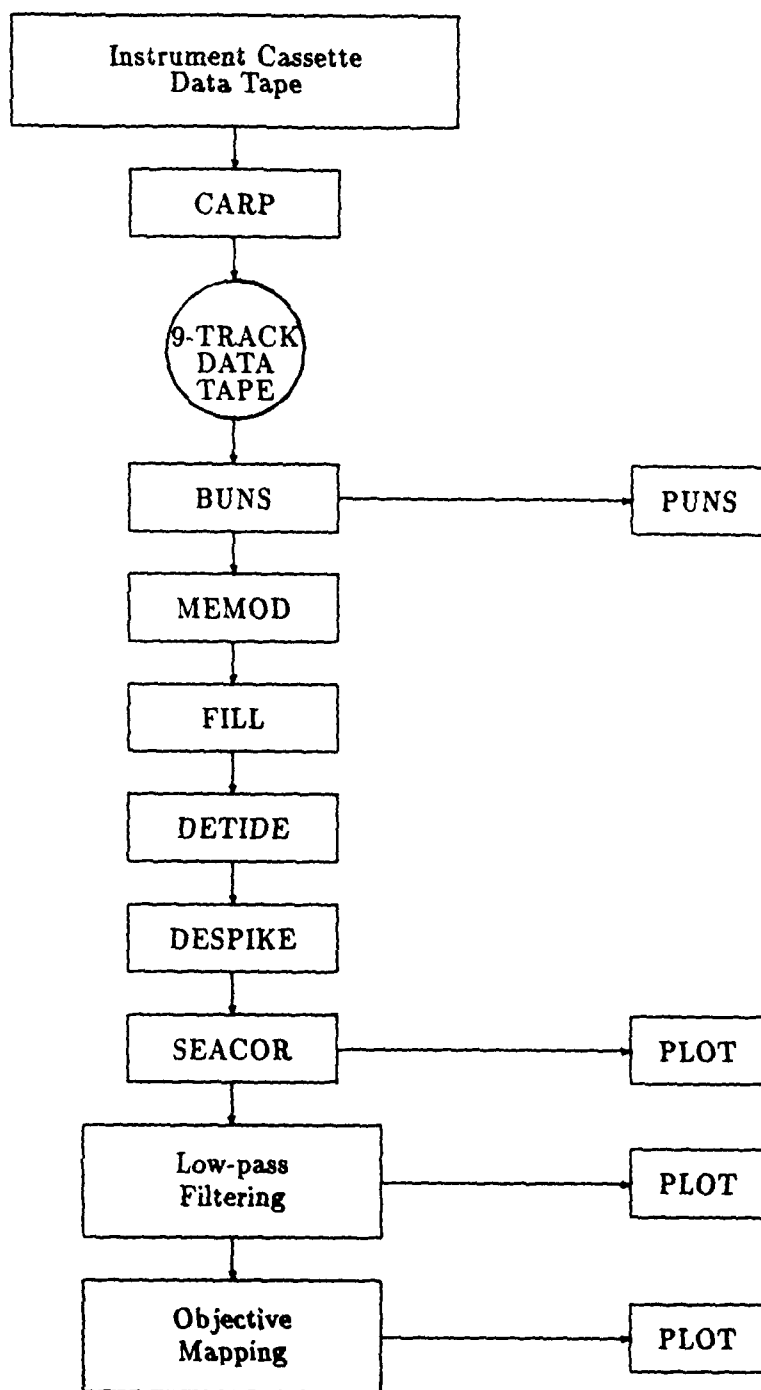


Figure 2: IES Data Processing Flowchart.

DESPIKE : Identifies and replaces travel time spikes with interpolated values.

SEACOR : Removes the effects of seasonal warming and cooling of the surface layers from the travel times. Plots of the half-hourly pressure, temperature and travel time are generated.

LOW PASS FILTERING : Convolves the travel times, pressures, and temperatures with a 40 hours low-pass Lanczos filter. The smoothed series are subsampled at six hour intervals and plotted.

OBJECTIVE MAPPING : Produces daily maps of the depth of the 12°C isotherm as documented in Watts, Tracey and Friedlander, 1988.

The **FESTSA** time series analysis package (Brooks, 1976), modified for the PRIME 750, was used to remove the higher frequency (tidal and inertial) motions from those with periods of several days or longer, which are the main focus of this project. The symmetric filter, with a Lanczos taper, was designed with the quarter power point at 0.025 cph and the tidal cycle attenuated by 60 dB. The half-hourly travel time, pressure, and temperature data were low-pass filtered and the smoothed output series (40 HRLP) had sampling intervals of six hours.

1.4.1 Travel Time Calibration

Variations in the travel times have been shown to be proportional to variations in the thermocline depth (Watts and Rossby, 1977; Watts and Wimbush, 1981). Calibration XBTs were taken at each IES site in order to convert the travel times (τ) into thermocline depths (ξ) according to the relation: $\xi = M\tau + B$, where M is a scale factor and the intercept B depends on the depth of the instrument. Regressions of τ versus ξ , performed for several instruments, show that the constant (M) value, $M = -19.0$ m/msec for the 12°C isotherm, is appropriate for all these Gulf Stream sites. The values of B used for each instrument are listed in the tables in Section 2. For practical purposes the main thermocline depth can be represented by the depth of an individual isotherm. For this work, we have chosen the 12°C isotherm since it is situated near the highest temperature gradients of the main thermocline and correlates well with τ (Rossby, 1969; Watts and Johns, 1982). The low-pass

filtered travel time records were scaled to the thermocline depths (Z_{12}) and these records are shown in Section 4. Since τ is resolved to 0.1 msec, the 40 HRLP Z_{12} scaled values are therefore resolved to ± 2 m. However, the accuracy of the offset parameter B is estimated to be ± 25 m for most instruments, judged from the agreement between the several calibration XBTs taken at each site. Relative to this, the 40 HRLP Z_{12} values are resolved to ± 2 m.

1.4.2 Thermocline Depth Mapping

Objective maps of the thermocline (Z_{12}) field in the array region have been produced at daily intervals from these records. The boxed region in Figure 1, oriented 045°T , is the region which has been mapped. The objective mapping techniques were developed by E. Carter (1983) and special adaptations for their application to the Gulf Stream frontal zone are discussed in Watts and Tracey (1985). Two results presented in this latter work are of particular importance to the objective mapping performed here: 1) If the mean field is removed, the perturbations have essentially isotropic correlation fields. 2) The space-time correlation functions used for the objective analysis are shown.

The objective analysis is performed on the "perturbation fields", which are obtained by removing the mean field from the input dataset and normalizing by the standard deviation. To represent the mean field, $\overline{Z_{12}}(x, y)$, where x is alongstream (045°T) and y is cross-stream (315°T), a third order polynomial was fitted to the mean values observed during the November 1986 to March 1987 deployment period. The function form of the polynomial was:

$$\overline{Z_{12}}(x, y) = B_0 + B_1x + B_2y + B_{11}x^2 + B_{12}xy + B_{22}y^2 + B_{111}x^3 + B_{112}x^2y + B_{122}xy^2 + B_{222}y^3$$

where (x, y) is the position in kilometers from the origin at 35°N , 74°W , B_0 is $0.76533772E + 03$, B_1 is $0.6320926E + 00$, B_2 is $-0.4103623E + 01$, B_{11} is $-0.8553885E - 02$, B_{12} is $0.1851212E - 01$, B_{22} is $-0.5083383E - 01$, B_{111} is $0.5500527E - 04$, B_{112} is $-0.9935370E - 04$, B_{122} is $-0.6128939E - 04$, and B_{222} is $0.3236166E - 03$. The standard deviation field, $\sigma(x, y)$, was defined as a function of the mean field depth, from a Gaussian form

representative of all IES records:

$$\sigma(x, y) = A + B \exp \left(- \left[\frac{\overline{Z_{12}}(x, y) - Z_o}{C} \right]^2 \right)$$

where A is 50 m, B is (200 m - A), C is 200 m, Z_o is 470 m, and $\overline{Z_{12}}(x, y)$ is the mean thermocline depth at that (x,y) location. Figure 10 shows both the mean and standard deviation fields in plain view. The objectively estimated error fields are shown in Figure 11.

For each output grid point, the objective mapping technique selects, from all the input data within a specified maximum time lag (T) and radial (R), the number of the points (N) which have the highest correlations. The output fields in Figure 12 result from specifying $N = 6$, $T = \pm 1$ days, $R = 120$ Km, and using the idealized correlation function (Watts and Tracey, 1985) with an assumed noise level $E = 0.05$.

The output of the objective mapping is the perturbation field on a full grid of points, with 20 Km grid spacing, within a 160 Km by 140 Km mapping region. The thermocline depth maps (shown in Figure 12) are obtained by renormalizing the perturbation field by the standard deviation and restoring the mean. Tracey et al. (1987) report an accuracy of 47 m for these output Z_{12} fields.

1.4.3 Temperature

Temperatures (Figure 6) were measured using thermistors (Yellow Springs International Corp., model 44032) controlled by Sea Data Corp. (model DC-37B) electronics cards installed in the IESs, in order to correct the pressure values for the temperature sensitivity of the transducer. The thermistor is inside the instrument, on the pressure transducer, rather than in the water. However, once the temperature probe has reached equilibrium with the surrounding waters, it also provides accurate measurements of the bottom temperature fluctuations (effectively low-pass filtered with a 40 hour e-folding equilibrium time). The first 24 half-hourly points were dropped prior to low-pass filtering, since the temperatures took 12 hours to reach equilibrium within 0.001°C . The accuracy of the temperature measurements is about 0.1°C , and the resolution is 0.0002°C .

1.4.4 Bottom Pressure

Digiquartz pressure sensor (models 46K-032 and 76KB-032) manufactured by Paroscientific, Inc. were used to measure bottom pressure. All pressure measurements were corrected for the temperature sensitivity of the transducer, using calibration coefficients purchased from the manufacturer. The half-hourly measured bottom pressures (Figure 4) are dominated by the tides, however for some of the instruments, the pressures also drift, 0(0.4 dbar), monotonically with time. Processing of the pressure measurements includes removing the long-term drift and tides as follows.

Tidal response analysis (Munk and Cartwright, 1977) was used to determine the tidal constituents for each instrument. The calculated tides were then removed from the pressure records. The amplitudes, H (dbar), and phases, G° (Greenwich epoch), of the constituents are given in the tables in Section 2.

In order to estimate and remove the long-term drift from the measurements, we made least-squares fits of exponential and exponential-linear curves to our data (Watts and Kontoyiannis, 1986). The mathematical formulas we used here were:

$$Drift = P_1[1 - \exp(P_2t)] + P_3$$

for the exponential curve and

$$Drift = P_1[1 - \exp(P_2t)] + P_3 + P_4t$$

for the exponential-linear curve. Here t is the time in hours, relative to the approximate deployment time, which is 13 hours before the first data point used. P_1 , P_2 , P_3 , and P_4 are free parameters determined for each instrument by the non-linear regression subroutine P3R of BMDP-79, a package of computer programs developed at the Health Science Computing Facility, UCLA (Dixon and Brown, 1979). These coefficients are listed in Section 2 for PIES87B1 and PIES87B3.

The half-hourly pressures are resolved to 0.001 dbar and the mean pressure is accurate to within 1.5 dbar. We estimate that the residual (drift and tide removed) bottom pressure

records, shown in Figure 5, have an accuracy (relative to their mean pressure) of better than 0.05 dbar (Watts and Kontoyiannis, 1986). The residual bottom pressure records were low-pass filtered (Figure 8) as mentioned above.

1.4.5 Time Base

The date and time were assigned to each sampling period. The tables in Section 2, report the hours, minutes, and seconds associated with the first and last sampling period as a six-digit number. All times are given as Greenwich Mean Time (GMT). For processing convenience, the times were converted into yearhours. Table 2 lists the yearhour which corresponds to 0000 GMT of each day for non-leap years. (For leap years, the yearhours can be determined by adding 24 to each day after February 28.) There are a total of 8760 hours in a standard year and 8784 hours in a leap year. The yearhours given in this report are referenced to January 1, 1987 at 0000 GMT, with measurements occurring between January and March 1987 assigned positive yearhours. Negative values correspond to the sampling period from November through December 1986.

1.5 Acoustic Ocean-Transport Meter Description

The acoustic transport meter, described in Chaplin and Watts (1986), is a new instrument which is presently under development. We conducted the first extensive test deployments of the ATM prototypes during the SYNOP Pilot Experiment.

The ATM consists of three separate components, a master transceiver and two slave transponders. These components are moored in a triangular pattern, at nominal spacings of 3 Km. The master is a microprocessor-controlled IES which has had its sampling scheme reprogrammed. The typical configuration has 32 measurements taken per hour at approximately 56 s intervals to allow ample time for all signals to be received and/or dissipated.

In addition to measuring transport, the master and slave components can perform other operations. The master functions as a traditional IES, measuring the thermocline depth at its deployment site. The two slaves can serve as navigation transponders for the Pegasus velocity profiler. During a Pegasus drop, the ATM is sent a coded signal and sampling is reduced to one measurement per hour so as not to interfere with the Pegasus acoustics.

Table 2: Yearhour Calendar for Non-Leap Years. Only the yearhour corresponding to 0000 GMT is listed for each day.

JAN				FEB				MAR				APR				MAY				JUNE			
DATE	YEAR	HOURL		DATE	YEAR	HOURL		DATE	YEAR	HOURL		DATE	YEAR	HOURL		DATE	YEAR	HOURL		DATE	YEAR	HOURL	
DAY	(0000Z)			DAY	(0000Z)			DAY	(0000Z)			DAY	(0000Z)			DAY	(0000Z)			DAY	(0000Z)		
1	1	0		1	321	744		1	601	1416		1	911	2160		1	1211	2880		1	1521	3624	
2	21	24		2	331	768		2	611	1440		2	921	2184		2	1221	2904		2	1531	3648	
3	31	48		3	341	792		3	621	1464		3	931	2208		3	1231	2928		3	1541	3672	
4	41	72		4	351	816		4	631	1488		4	941	2232		4	1241	2952		4	1551	3696	
5	51	96		5	361	840		5	641	1512		5	951	2256		5	1251	2976		5	1561	3720	
6	61	120		6	371	864		6	651	1536		6	961	2280		6	1261	3000		6	1571	3744	
7	71	144		7	381	888		7	661	1560		7	971	2304		7	1271	3024		7	1581	3768	
8	81	168		8	391	912		8	671	1584		8	981	2328		8	1281	3048		8	1591	3792	
9	91	192		9	401	936		9	681	1608		9	991	2352		9	1291	3072		9	1601	3816	
10	101	216		10	411	960		10	691	1632		10	1001	2376		10	1301	3096		10	1611	3840	
11	111	240		11	421	984		11	701	1656		11	1011	2400		11	1311	3120		11	1621	3864	
12	121	264		12	431	1008		12	711	1680		12	1021	2424		12	1321	3144		12	1631	3888	
13	131	288		13	441	1032		13	721	1704		13	1031	2448		13	1331	3168		13	1641	3912	
14	141	312		14	451	1056		14	731	1728		14	1041	2472		14	1341	3192		14	1651	3936	
15	151	336		15	461	1080		15	741	1752		15	1051	2496		15	1351	3216		15	1661	3960	
16	161	360		16	471	1104		16	751	1776		16	1061	2520		16	1361	3240		16	1671	3984	
17	171	384		17	481	1128		17	761	1800		17	1071	2544		17	1371	3264		17	1681	4008	
18	181	408		18	491	1152		18	771	1824		18	1081	2568		18	1381	3288		18	1691	4032	
19	191	432		19	501	1176		19	781	1848		19	1091	2592		19	1391	3312		19	1701	4056	
20	201	456		20	511	1200		20	791	1872		20	1101	2616		20	1401	3336		20	1711	4080	
21	211	480		21	521	1224		21	801	1896		21	1111	2640		21	1411	3360		21	1721	4104	
22	221	504		22	531	1248		22	811	1920		22	1121	2664		22	1421	3384		22	1731	4128	
23	231	528		23	541	1272		23	821	1944		23	1131	2688		23	1431	3408		23	1741	4152	
24	241	552		24	551	1296		24	831	1968		24	1141	2712		24	1441	3432		24	1751	4176	
25	251	576		25	561	1320		25	841	1992		25	1151	2736		25	1451	3456		25	1761	4200	
26	261	600		26	571	1344		26	851	2016		26	1161	2760		26	1461	3480		26	1771	4224	
27	271	624		27	581	1368		27	861	2040		27	1171	2784		27	1471	3504		27	1781	4248	
28	281	648		28	591	1392		28	871	2064		28	1181	2808		28	1481	3528		28	1791	4272	
29	291	672						29	881	2088		29	1191	2832		29	1491	3552		29	1801	4296	
30	301	696						30	891	2112		30	1201	2856		30	1501	3576		30	1811	4320	
31	311	720						31	901	2136						31	1511	3600					

JULY				AUG				SEPT				OCT				NOV				DEC			
DATE	YEAR	HOURL		DATE	YEAR	HOURL		DATE	YEAR	HOURL		DATE	YEAR	HOURL		DATE	YEAR	HOURL		DATE	YEAR	HOURL	
DAY	(0000Z)			DAY	(0000Z)			DAY	(0000Z)			DAY	(0000Z)			DAY	(0000Z)			DAY	(0000Z)		
1	1821	4344		1	2131	5088		1	2441	5832		1	2741	6552		1	3051	7296		1	3351	8016	
2	1831	4368		2	2141	5112		2	2451	5856		2	2751	6576		2	3061	7320		2	3361	8040	
3	1841	4392		3	2151	5136		3	2461	5880		3	2761	6600		3	3071	7344		3	3371	8064	
4	1851	4416		4	2161	5160		4	2471	5904		4	2771	6624		4	3081	7368		4	3381	8088	
5	1861	4440		5	2171	5184		5	2481	5928		5	2781	6648		5	3091	7392		5	3391	8112	
6	1871	4464		6	2181	5208		6	2491	5952		6	2791	6672		6	3101	7416		6	3401	8136	
7	1881	4488		7	2191	5232		7	2501	5976		7	2801	6696		7	3111	7440		7	3411	8160	
8	1891	4512		8	2201	5256		8	2511	6000		8	2811	6720		8	3121	7464		8	3421	8184	
9	1901	4536		9	2211	5280		9	2521	6024		9	2821	6744		9	3131	7488		9	3431	8208	
10	1911	4560		10	2221	5304		10	2531	6048		10	2831	6768		10	3141	7512		10	3441	8232	
11	1921	4584		11	2231	5328		11	2541	6072		11	2841	6792		11	3151	7536		11	3451	8256	
12	1931	4608		12	2241	5352		12	2551	6096		12	2851	6816		12	3161	7560		12	3461	8280	
13	1941	4632		13	2251	5376		13	2561	6120		13	2861	6840		13	3171	7584		13	3471	8304	
14	1951	4656		14	2261	5400		14	2571	6144		14	2871	6864		14	3181	7608		14	3481	8328	
15	1961	4680		15	2271	5424		15	2581	6168		15	2881	6888		15	3191	7632		15	3491	8352	
16	1971	4704		16	2281	5448		16	2591	6192		16	2891	6912		16	3201	7656		16	3501	8376	
17	1981	4728		17	2291	5472		17	2601	6216		17	2901	6936		17	3211	7680		17	3511	8400	
18	1991	4752		18	2301	5496		18	2611	6240		18	2911	6960		18	3221	7704		18	3521	8424	
19	2001	4776		19	2311	5520		19	2621	6264		19	2921	6984		19	3231	7728		19	3531	8448	
20	2011	4800		20	2321	5544		20	2631	6288		20	2931	7008		20	3241	7752		20	3541	8472	
21	2021	4824		21	2331	5568		21	2641	6312		21	2941	7032		21	3251	7776		21	3551	8496	
22	2031	4848		22	2341	5592		22	2651	6336		22	2951	7056		22	3261	7800		22	3561	8520	
23	2041	4872		23	2351	5616		23	2661	6360		23	2961	7080		23	3271	7824		23	3571	8544	
24	2051	4896		24	2361	5640		24	2671	6384		24	2971	7104		24	3281	7848		24	3581	8568	
25	2061	4920		25	2371	5664		25	2681	6408		25	2981	7128		25	3291	7872		25	3591	8592	
26	2071	4944		26	2381	5688		26	2691	6432		26	2991	7152		26	3301	7896		26	3601	8616	
27	2081	4968		27	2391	5712		27	2701	6456		27	3001	7176		27	3311	7920		27	3611	8640	
28	2091	4992		28	2401	5736		28	2711	6480		28	3011	7200		28	3321	7944		28	3621	8664	
29	2101	5016		29	2411	5760		29	2721	6504		29	3021	7224		29	3331	7968		29	3631	8688	
30	2111	5040		30	2421	5784		30	2731	6528		30	3031	7248		30	3341	7992		30	3641	8712	
31	2121	5064		31	2431	5808						31	3041	7272						31	3641	8736	

After the Pegasus operations have been completed, normal sampling resumes

Unfortunately during the Pilot Experiment, the ATMs did not function correctly. Two unrelated problems occurred which resulted in poor data returns. First, deploying the three ATM components at just the right spacings so that all the required acoustic signals are received without interfering with each other or with extraneous echos is a more subtle and difficult job than we had realized. Consequently, the deployment sites of the three ATM components were not optimal, and some of the acoustic signals required for the transport calculations either were not recorded or interfered with each other's detected transit time. Hence, in this report only thermocline depth measurements are reported for the ATMs.

Secondly, after operating normally for several days, both instruments automatically switched from the "normal" sampling mode into the "Pegasus" sampling mode. For one instrument, ATM87B2, even the Pegasus-mode was unusual with 8 measurements made at irregular intervals during each hour. Thus special data processing was required to obtain accurate thermocline depth values from the travel time measurements.

The data records of both ATM87B2 and ATM87B4 were split into two sections based on the sampling modes. Different processing was performed on the different sections.

Both instruments sampled normally (32 measurements per hour) during the first portions. These travel time data were grouped into hourly "bursts" and processed as in Section 1.4 for an IES through the MEMOD and DESPIKE programs. Since these initial records were only about five days long, the high frequency motions were removed using a 12-hour lowpass-filter in place of the typical 40-hour lowpass-filter. The output data were subsampled at 6-hour intervals and scaled to thermocline depths. Since these records are very short, they are not shown in Figures 3.2 and 7.2. However the data have been used to contribute to the objective maps shown in Section 5.

For the two instruments, the second portions (Pegasus-mode) of the travel time records were processed differently. For ATM87B2, with only 8 samples per hour, the data were grouped into 12-hour "bursts" prior to IES processing and removing the travel time spikes. The data for ATM87B4, with only one sample per hour, were similarly grouped and processed, except in 24-hour "bursts". For both instruments, the start time for each "burst" is stepped forward at a 6 hour interval (the bursts overlap). The processed vertical travel time data from the ATMs are shown in Figure 3.2. Lowpass-filtering was performed using a 96-hour Lanczos filter. The filtered data (Figure 7.2) have a sampling interval of 24 hours

and were scaled to thermocline depths in the same manner as for the other IESs.

1.6 Data Recovery

Table 1 summarizes the data returns from each of the IESs and ATMs. All nine instruments were recovered, giving a recovery rate of 100%. IES87C1 ceased functioning properly about one month after the instrument was launched. All the remaining instruments performed successfully, yielding a 91% data return for the travel time measurements. Complete records were obtained from all three bottom pressure gauges; however the data record from one of these (PIES87B6) had large jumps, indicating its sensor malfunctioned, thus the recovery rate for the bottom pressure data was only 67%. Complete records were obtained from all three temperature gauges; thus the return rate was 100% for these data.

2 Individual Site and Record Information Tables

The following tables provide informations about the location, dates, and basic statistics on the data records. Each table documents a single instrument site.

General site information, such as position, bottom depth, and launch and recovery times, is given first. Subsequently, details about the travel time, bottom pressure, temperature and thermocline depth records plotted in Section 3 and 4 are tabulated. For each plot, the times associated with the first and last data point are supplied. All yearhours are referenced to January 1, 1987 at 0000 GMT. Measurements made during the calendar year prior to the reference date are given as negative yearhours.

The first order statistics (minimum, maximum, mean, and standard deviation) were calculated for the half-hourly and 40 HRLP records for each variable of standard IES and PIES, and for the six-hourly and 96 HRLP records for that of two ATMs. These are also presented in the following tables.

**Table 3. Site and Record Information for
IES87A1**

Serial Number: 043
 Type of Travel Time Detector: TTC
 Number of Pings per Sampling: 20
 Additional Sensors: None

POSITION: 35°16.12 N DEPTH: 2660 m
 74°32.94 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 28, 1986	023900	EN152
RECOVERY:	Mar 2, 1987	190400	EN156

TRAVEL TIME RECORDS

Fig. 3.1

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	033135	-812.4736
LAST DATA POINT:	Mar 2, 1987	190133	1459.0258

Number of Points: 4544
 Sampling Interval: 0.5 hrs

Minimum $\tau = 3.52552$ s Mean = 3.53130 s
 Maximum $\tau = 3.54078$ s Standard Deviation = 0.00263 s

40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.1

Z_{12} Conversion equation: $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$
 where $B = 67541.63$ m
 $\tau_d =$ Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 29, 1986	120000	-780.00
LAST DATA POINT:	Mar 1, 1987	120000	1428.00

Number of Points: 369
 Sampling Interval: 6.0 hrs

Minimum $Z_{12} = 313.34$ m Mean = 447.74 m
 Maximum $Z_{12} = 522.71$ m Standard Deviation = 46.97 m

**Table 4. Site and Record Information for
IES87A2**

Serial Number: 045
Type of Travel Time Detector: TTC
Number of Pings per Sampling: 20
Additional Sensors: None

POSITION: 34°58.08 N DEPTH: 3280 m
74°07.89 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 27, 1986	230500	EN152
RECOVERY:	Mar 2, 1987	143300	EN156

TRAVEL TIME RECORDS

Fig. 3.1

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	000135	-815.9736
LAST DATA POINT:	Mar 2, 1987	143133	1454.5258

Number of Points: 4542
Sampling Interval: 0.5 hrs

Minimum $\tau = 4.34647$ s Mean = 4.35049 s
Maximum $\tau = 4.35414$ s Standard Deviation = 0.00108 s

40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.1

Z_{12} Conversion equation: $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$

where $B = 83377.92$ m

$\tau_d =$ Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 29, 1986	060000	-786.00
LAST DATA POINT:	Mar 1, 1987	060000	1422.00

Number of Points: 369
Sampling Interval: 6.0 hrs

Minimum $Z_{12} = 682.58$ m Mean = 718.22 m
Maximum $Z_{12} = 757.91$ m Standard Deviation = 16.05 m

**Table 5. Site and Record Information for
PIES87B1**

Serial Number: 058
 Type of Travel Time Detector: TTC
 Number of Pings per Sampling: 24
 Additional Sensors: Pressure and Temperature
 Pressure Sensor Serial Number: 19327

POSITION: 35°45.64 N DEPTH: 1950 m
 74°27.93 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 25, 1986	205600	EN152
RECOVERY:	Feb 28, 1987	093836	EN156

TRAVEL TIME RECORDS

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 25, 1986	213151	-866.4692
LAST DATA POINT:	Feb 28, 1987	093151	1401.5308

Number of Points: 4537
 Sampling Interval: 0.5 hrs

Minimum $\tau = 0.19395$ s Mean = 0.20100 s
 Maximum $\tau = 0.20586$ s Standard Deviation = 0.00193 s

40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.2

Z_{12} Conversion equation: $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$

where B = 4045.00 m

τ_d = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	060000	-834.00
LAST DATA POINT:	Feb 27, 1987	000000	1368.00

Number of Points: 368
 Sampling Interval: 6.0 hrs

Minimum $Z_{12} = 164.37$ m Mean = 226.57 m
 Maximum $Z_{12} = 313.92$ m Standard Deviation = 33.06 m

PIES87B1 (continue)

MEASURED PRESSURE RECORDS

Fig. 4

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 25, 1986	213151	-866.4692
LAST DATA POINT:	Feb 28, 1987	093151	1401.5308

Number of Points: 4537

Sampling Interval: 0.5 hrs

Minimum = 1964.16 dbar

Mean = 1964.88 dbar

Maximum = 1965.79 dbar Standard Deviation = 0.33140 dbar

RESIDUAL PRESSURE RECORDS

Fig. 5

$$P_{\text{residual}} = P_{\text{measured}} - \text{MEAN} - \text{DRIFT} - \text{TIDE}$$

$$\text{DRIFT} = P_1[1 - \exp(P_2 t)] + P_3 + P_4 t$$

where t = Time of sample in hours, starting with
t = 13.0 hrs for the first data point

$$P_1 = 1.167470 \text{ dbar}$$

$$P_2 = -0.000321 \text{ dbar}$$

$$P_3 = 0.078548 \text{ dbar}$$

$$P_4 = 0.000231 \text{ dbar}$$

TIDE calculated from the following constituents:

	M2	N2	S2	K2	K1	O1	P1	Q1
H (dbar):	.42831	.10012	.09006	.02148	.09056	.07172	.02964	.01654
G°:	353.09	335.93	19.74	21.35	182.59	188.09	183.70	183.94

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	093151	-854.4692
LAST DATA POINT:	Feb 28, 1987	093151	1401.5308

Number of Points: 4513

Sampling Interval: 0.5 hrs

Minimum = -0.1354 dbar

Mean = 0.0005 dbar

Maximum = 0.1181 dbar Standard Deviation = 0.0309 dbar

PIES87B1 (continue)

40HRLP PRESSURE RECORDS

Fig. 8

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	180000	-822.0000
LAST DATA POINT:	Feb 27, 1987	000000	1368.0000

Number of Points: 366

Sampling Interval: 6.0 hrs

Minimum = -0.1099 dbar

Mean = 0.0003 dbar

Maximum = 0.0562 dbar Standard Deviation = 0.0235 dbar

TEMPERATURE RECORDS

Fig. 6

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 25, 1986	213151	-866.4692
LAST DATA POINT:	Feb 28, 1987	093151	1401.5308

Number of Points: 4537

Sampling Interval: 0.5 hrs

Minimum = 3.490 °C

Mean = 3.784 °C

Maximum = 3.991 °C Standard Deviation = 0.103 °C

40HRLP TEMPERATURE RECORDS

Fig. 9

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	180000	-822.0000
LAST DATA POINT:	Feb 27, 1987	000000	1368.0000

Number of Points: 366

Sampling Interval: 6.0 hrs

Minimum = 3.533 °C

Mean = 3.784 °C

Maximum = 3.953 °C Standard Deviation = 0.086 °C

**Table 6. Site and Record Information for
ATM87B2**

Serial Number: 064
 Type of Travel Time Detector: TTD
 Number of Pings per Sampling: refer to Sec. 1.5
 Additional Sensors: None

POSITION: 35°40.67 N DEPTH: 2300 m
 74°23.52 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 30, 1986	215700	EN152
RECOVERY:	Feb 28, 1987	065600	EN156

RAW TRAVEL TIME RECORDS

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Dec 4, 1986	141742	-657.7051
LAST DATA POINT:	Feb 28, 1987	011742	1393.2951

Number of Points: 343
 Sampling Interval: 6.0 hrs

Minimum $\tau = 3.02466$ s Mean = 3.03044 s
 Maximum $\tau = 3.03808$ s Standard Deviation = 0.00254 s

96HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.2

Z_{12} Conversion equation: $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$
 where $B = 57875.36$ m
 $\tau_d =$ Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Dec 7, 1986	120000	-588.00
LAST DATA POINT:	Feb 25, 1987	120000	1332.00

Number of Points: 81
 Sampling Interval: 24 hrs

Minimum $Z_{12} = 195.84$ m Mean = 297.67 m
 Maximum $Z_{12} = 378.48$ m Standard Deviation = 0.0047 m

**Table 7. Site and Record Information for
PIES87B3**

Serial Number: 053
 Type of Travel Time Detector: TTC
 Number of Pings per Sampling: 24
 Additional Sensors: Pressure and Temperature
 Pressure Sensor Serial Number: 17849

POSITION: 35°37.07 N DEPTH: 2665 m
 74°13.92 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 26, 1986	030200	EN152
RECOVERY:	Feb 28, 1987	130346	EN156

TRAVEL TIME RECORDS

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	033152	-860.4690
LAST DATA POINT:	Feb 28, 1987	130152	1405.0310

Number of Points: 4532
 Sampling Interval: 0.5 hrs

Minimum $\tau = 0.35106$ s Mean = 0.35759 s
 Maximum $\tau = 0.36869$ s Standard Deviation = 0.00331 s

40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.2

Z_{12} Conversion equation: $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$
 where $B = 7224.39$ m
 $\tau_d =$ Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	120000	-828.00
LAST DATA POINT:	Feb 27, 1987	060000	1374.00

Number of Points: 368
 Sampling Interval: 6.0 hrs

Minimum $Z_{12} = 245.69$ m Mean = 430.42 m
 Maximum $Z_{12} = 529.52$ m Standard Deviation = 61.07 m

PIES87B3 (continue)

MEASURED PRESSURE RECORDS

Fig. 4

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	033152	-860.4690
LAST DATA POINT:	Feb 28, 1987	130152	1405.0310

Number of Points: 4532

Sampling Interval: 0.5 hrs

Minimum = 2707.75 dbar

Mean = 2708.47 dbar

Maximum = 2709.34 dbar Standard Deviation = 0.33335 dbar

RESIDUAL PRESSURE RECORDS

Fig. 5

$$P_{\text{residual}} = P_{\text{measured}} - \text{MEAN} - \text{DRIFT} - \text{TIDE}$$

$$\text{DRIFT} = P_1[1 - \exp(-P_2 t)] + P_3$$

where t = Time of sample in hours, starting with
t = 13.0 hrs for the first data point

$$P_1 = 0.8711981 \text{ dbar}$$

$$P_2 = 0.0000230 \text{ dbar}$$

$$P_3 = 0.0237850 \text{ dbar}$$

TIDE calculated from the following constituents:

	M2	N2	S2	K2	K1	O1	P1	Q1
H (dbar):	.43050	.10010	.08999	.02143	.09059	.07073	.02959	.01645
G°:	353.13	335.75	19.66	21.12	183.03	187.32	184.32	180.85

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	153152	-848.4688
LAST DATA POINT:	Feb 28, 1987	130152	1405.0312

Number of Points: 4508

Sampling Interval: 0.5 hrs

Minimum = -0.1532 dbar

Mean = -0.0001 dbar

Maximum = 0.1229 dbar Standard Deviation = 0.0350 dbar

PIES87B3 (continue)**40HRLP PRESSURE RECORDS**

Fig. 8

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	000000	-816.0000
LAST DATA POINT:	Feb 27, 1987	060000	1374.0000

Number of Points: 366
Sampling Interval: 6.0 hrs

Minimum = -0.1216 dbar Mean = 0.0009 dbar
Maximum = 0.0719 dbar Standard Deviation = 0.0294 dbar

TEMPERATURE RECORDS

Fig. 6

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	033152	-860.4690
LAST DATA POINT:	Feb 28, 1987	130152	1405.0310

Number of Points: 4532
Sampling Interval: 0.5 hrs

Minimum = 2.570 °C Mean = 2.837 °C
Maximum = 3.088 °C Standard Deviation = 0.124 °C

40HRLP TEMPERATURE RECORDS

Fig. 9

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	000000	-816.0000
LAST DATA POINT:	Feb 27, 1987	060000	1374.0000

Number of Points: 366
Sampling Interval: 6.0 hrs

Minimum = 2.578 °C Mean = 2.834 °C
Maximum = 3.063 °C Standard Deviation = 0.114 °C

**Table 8. Site and Record Information for
ATM87B4**

Serial Number: 063
 Type of Travel Time Detector: TTD
 Number of Pings per Sampling: refer to Sec. 1.5
 Additional Sensors: None

POSITION: 35°26.50 N DEPTH: 3085 m
 73°59.47 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 24, 1986	062400	EN152
RECOVERY:	Feb 28, 1987	164900	EN156

RAW TRAVEL TIME RECORDS

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 30, 1986	112611	-756.5635
LAST DATA POINT:	Feb 21, 1987	052611	1229.4365

Number of Points: 332
 Sampling Interval: 6.0 hrs

Minimum $\tau = 4.07544$ s Mean = 4.07870 s
 Maximum $\tau = 4.08579$ s Standard Deviation = 0.01749 s

96HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.2

Z_{12} Conversion equation: $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$
 where B = 78181.09 m
 τ_d = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Dec 2, 1986	120000	-708.00
LAST DATA POINT:	Feb 18, 1987	120000	1'64.00

Number of Points: 79
 Sampling Interval: 24 hrs

Minimum $Z_{12} = 562.65$ m Mean = 684.56 m
 Maximum $Z_{12} = 732.31$ m Standard Deviation = 0.0034 m

**Table 9. Site and Record Information for
IES87B5**

Serial Number: 052
 Type of Travel Time Detector: TTC
 Number of Pings per Sampling: 20
 Additional Sensors: None

POSITION: 35°22.06 N DEPTH: 3280 m
 73°53.06 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 26, 1986	175600	EN152
RECOVERY:	Feb 28, 1987	164500	EN156

TRAVEL TIME RECORDS

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	183135	-845.4736
LAST DATA POINT:	Feb 28, 1987	163133	1408.5258

Number of Points: 4509
 Sampling Interval: 0.5 hrs

Minimum $\tau = 4.36937$ s Mean = 4.37362 s
 Maximum $\tau = 4.37918$ s Standard Deviation = 0.00130 s

40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.2

Z_{12} Conversion equation: $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$
 where $B = 83818.94$ m
 $\tau_d =$ Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	000000	-816.00
LAST DATA POINT:	Feb 27, 1987	060000	1374.00

Number of Points: 366
 Sampling Interval: 6.0 hrs

Minimum $Z_{12} = 641.63$ m Mean = 719.65 m
 Maximum $Z_{12} = 775.03$ m Standard Deviation = 21.17 m

**Table 10. Site and Record Information for
PIES87B6**

Serial Number: 054
 Type of Travel Time Detector: TTC
 Number of Pings per Sampling: 24
 Additional Sensors: Pressure and Temperature
 Pressure Sensor Serial Number: 18426

POSITION: 35°14.54 N DEPTH: 3555 m
 73°42.92 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 27, 1986	032900	EN152
RECOVERY:	Feb 28, 1987	211200	EN156

TRAVEL TIME RECORDS

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	043220	-835.4612
LAST DATA POINT:	Feb 28, 1987	210220	1413.0388

Number of Points: 4498
 Sampling Interval: 0.5 hrs

Minimum $\tau = 0.34298$ s Mean = 0.34741 s
 Maximum $\tau = 0.35101$ s Standard Deviation = 0.00117 s

40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.2

Z_{12} Conversion equation: $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$

where B = 7365.00 m

τ_d = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	120000	-804.00
LAST DATA POINT:	Feb 27, 1987	120000	1380.00

Number of Points: 365
 Sampling Interval: 6.0 hrs

Minimum $Z_{12} = 719.31$ m Mean = 763.74 m
 Maximum $Z_{12} = 810.76$ m Standard Deviation = 18.88 m

PIES87B6 (continue)**MEASURED PRESSURE RECORDS**

Fig. 4

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	043220	-835.4612
LAST DATA POINT:	Feb 28, 1987	210220	1413.0388

Number of Points: 4498

Sampling Interval: 0.5 hrs

(Pressure record is jumpy)

TEMPERATURE RECORDS

Fig. 6

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	043220	-835.4612
LAST DATA POINT:	Feb 28, 1987	210220	1413.0388

Number of Points: 4498

Sampling Interval: 0.5 hrs

Minimum = 2.324 °C

Mean = 2.372 °C

Maximum = 2.458 °C Standard Deviation = 0.045 °C

40HRLP TEMPERATURE RECORDS

Fig. 9

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 29, 1986	000000	-792.0000
LAST DATA POINT:	Feb 27, 1987	120000	1380.0000

Number of Points: 363

Sampling Interval: 6.0 hrs

Minimum = 2.324 °C

Mean = 2.372 °C

Maximum = 2.442 °C Standard Deviation = 0.030 °C

**Table 11. Site and Record Information for
IES87B7**

Serial Number: 036
Type of Travel Time Detector: TTC
Number of Pings per Sampling: 20
Additional Sensors: None

POSITION: 35°06.05 N DEPTH: 3800 m
73°31.94 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 27, 1986	080900	EN152
RECOVERY:	Mar 1, 1987	001700	EN156

TRAVEL TIME RECORDS

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	090135	-830.9736
LAST DATA POINT:	Mar 1, 1987	000133	1416.0258

Number of Points: 4495
Sampling Interval: 0.5 hrs

Minimum $\tau = 5.07445$ s Mean = 5.07846 s
Maximum $\tau = 5.08267$ s Standard Deviation = 0.001394 s

40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.2

Z_{12} Conversion equation: $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$
where $B = 97250.04$ m
 $\tau_d =$ Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	180000	-798.00
LAST DATA POINT:	Feb 27, 1987	120000	1386.00

Number of Points: 365
Sampling Interval: 6.0 hrs

Minimum $Z_{12} = 713.03$ m Mean = 758.96 m
Maximum $Z_{12} = 807.02$ m Standard Deviation = 22.45 m

**Table 12. Site and Record Information for
IES87C1**

Serial Number: 041
 Type of Travel Time Detector: TTC
 Number of Pings per Sampling: 20
 Additional Sensors: None

POSITION: 36°02.80 N DEPTH: 2880 m
 73°52.90 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 23, 1986	060700	EN152
RECOVERY:	Mar 3, 1987	044800	EN156

TRAVEL TIME RECORDS

Fig. 3.1

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 23, 1986	064635	-929.2236
LAST DATA POINT:	Dec 24, 1986	064635	-185.2236

Number of Points: 1489
 Sampling Interval: 0.5 hrs

Minimum $\tau = 3.94585$ s Mean = 3.95146 s
 Maximum $\tau = 3.95906$ s Standard Deviation = 0.00259 s

40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.1

Z_{12} Conversion equation: $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$

where B = 75455.93 m

τ_d = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 24, 1986	180000	-894.00
LAST DATA POINT:	Dec 23, 1986	000000	-216.00

Number of Points: 114
 Sampling Interval: 6.0 hrs

Minimum $Z_{12} = 274.26$ m Mean = 373.72 m
 Maximum $Z_{12} = 460.27$ m Standard Deviation = 44.67 m

**Table 13. Site and Record Information for
IES87C2**

Serial Number: 061
 Type of Travel Time Detector: TTC
 Number of Pings per Sampling: 20
 Additional Sensors: None

POSITION: 35°43.98 N DEPTH: 3535 m
 73°29.98 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 27, 1986	141200	EN152
RECOVERY:	Mar 3, 1987	220600	EN156

TRAVEL TIME RECORDS

Fig. 3.1

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	151635	-824.7236
LAST DATA POINT:	Mar 3, 1987	214633	1485.7758

Number of Points: 4622
 Sampling Interval: 0.5 hrs

Minimum $\tau = 4.71669$ s Mean = 4.72040 s
 Maximum $\tau = 4.73019$ s Standard Deviation = 0.00216 s

40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.1

Z_{12} Conversion equation: $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$
 where $B = 90375.20$ m
 $\tau_d =$ Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 29, 1986	000000	-792.00
LAST DATA POINT:	Mar 2, 1987	120000	1452.00

Number of Points: 375
 Sampling Interval: 6.0 hrs

Minimum $Z_{12} = 514.61$ m Mean = 687.47 m
 Maximum $Z_{12} = 731.10$ m Standard Deviation = 39.48 m

3 Half-hourly Data For Each Cross-stream Line

Plots of the travel time records from each instrument are presented first. These are followed by the measured and residual pressure records and the temperature data for the instruments which had those additional sensors.

These are grouped by cross-stream line, with the northwesternmost IES on each line plotted at the top of the figure. Each plot is labelled with the instrument name in the upper left corner. The time scale is the same for all plots, with each increment corresponding to 5 days. The axis begins on 1200 GMT of the first date labelled.

Vertical scale for each variable is consistent between instruments. Each increment corresponds to 5 msec for the travel time records, to 0.5 dbar for the measured bottom pressure measurements, to 0.05 dbar for the residual bottom pressure data, and to 0.1°C for the temperatures.

The sampling interval of the IESs and PIEs is normally 0.5 hours; the actual interval for each instrument is listed Section 2. ATMs have a 6 hour sampling interval. The length and the start and end times of the data records are also listed in the previous section.

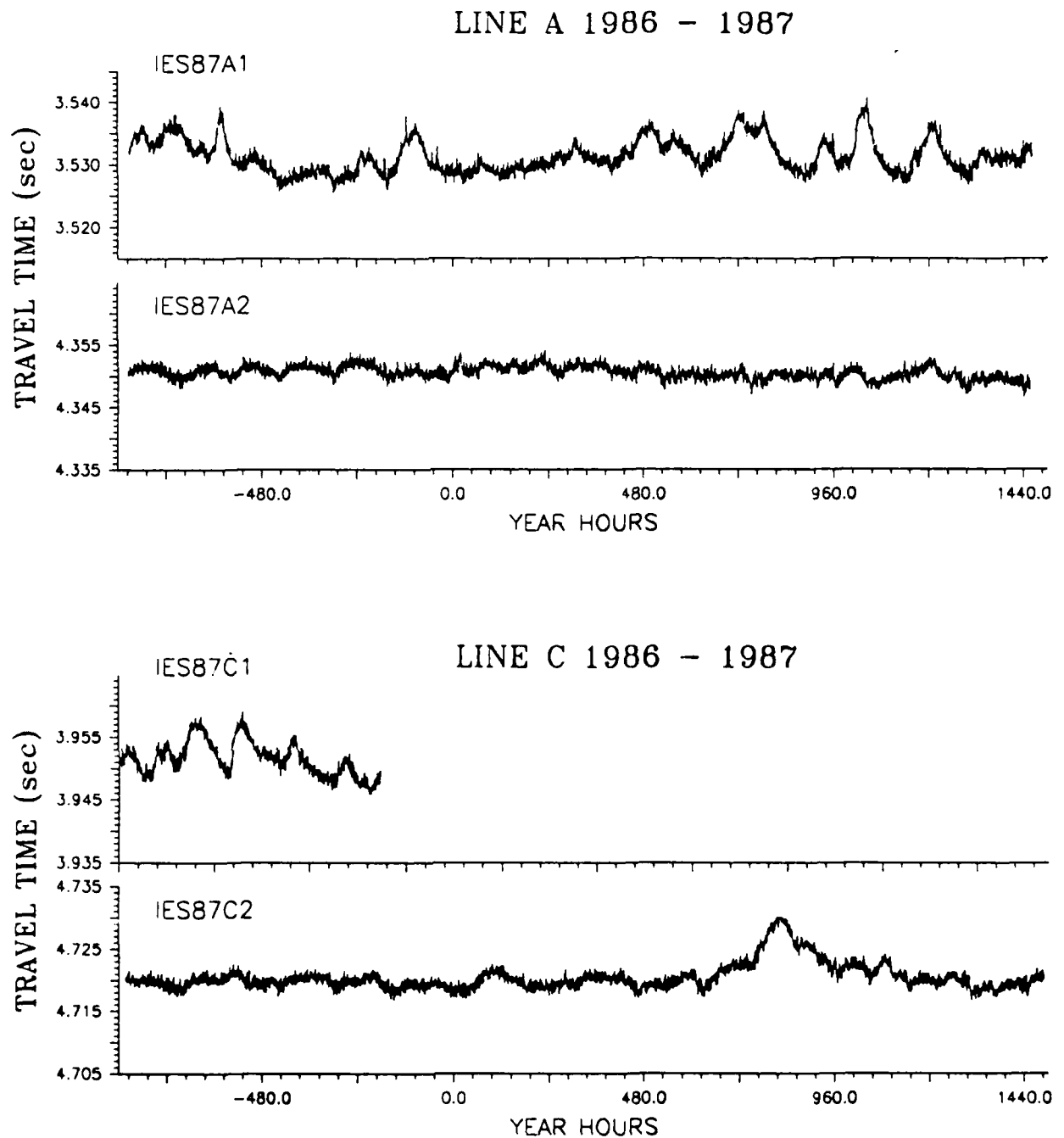


Figure 3.1: Travel time records for Line A and C at half-hourly intervals. The start and end times and records lengths are listed in Section 2.

LINE B 1986 - 1987

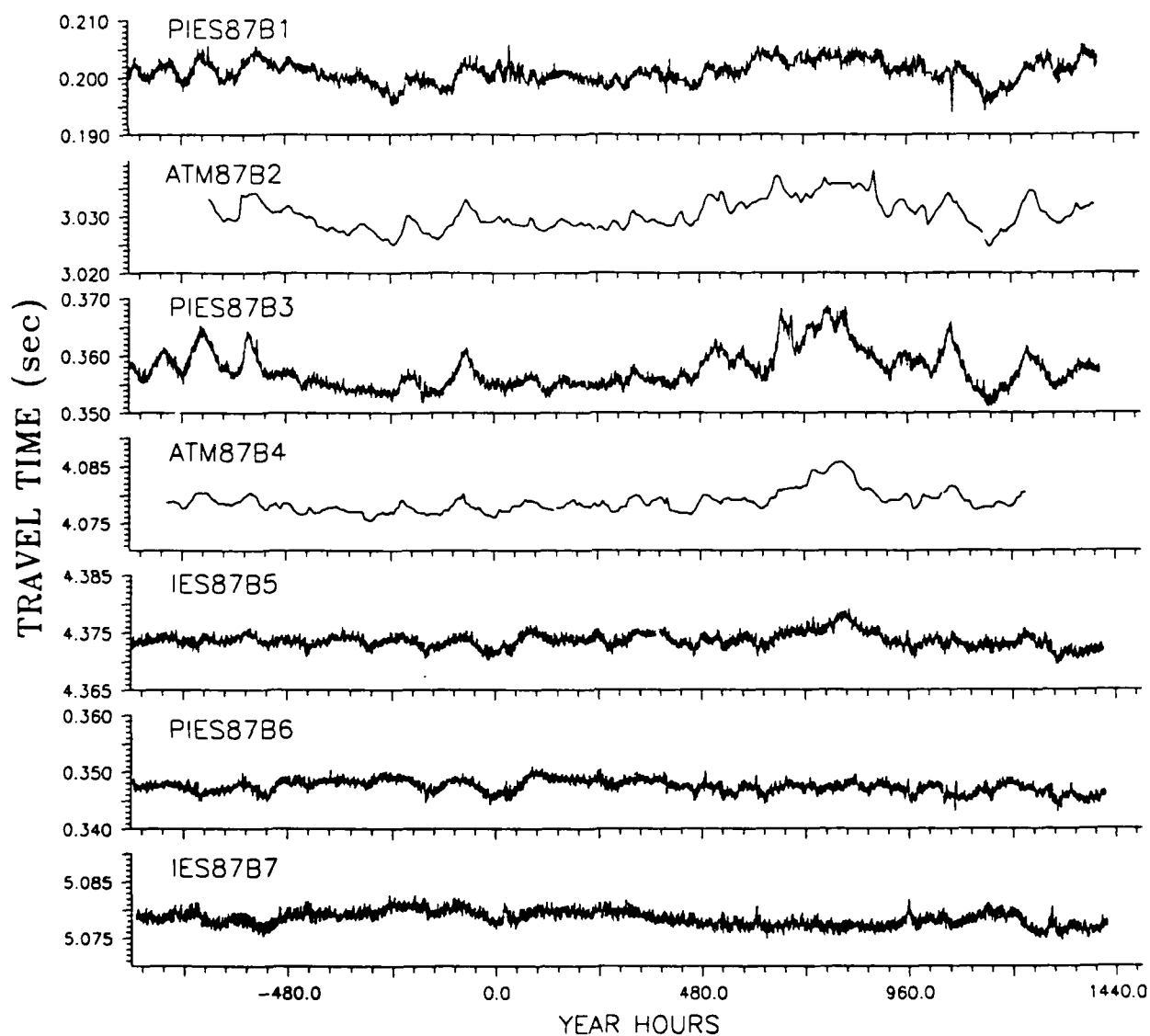


Figure 3.2: Travel time records for Line B at half-hourly intervals: at six-hourly intervals for A.I.s.

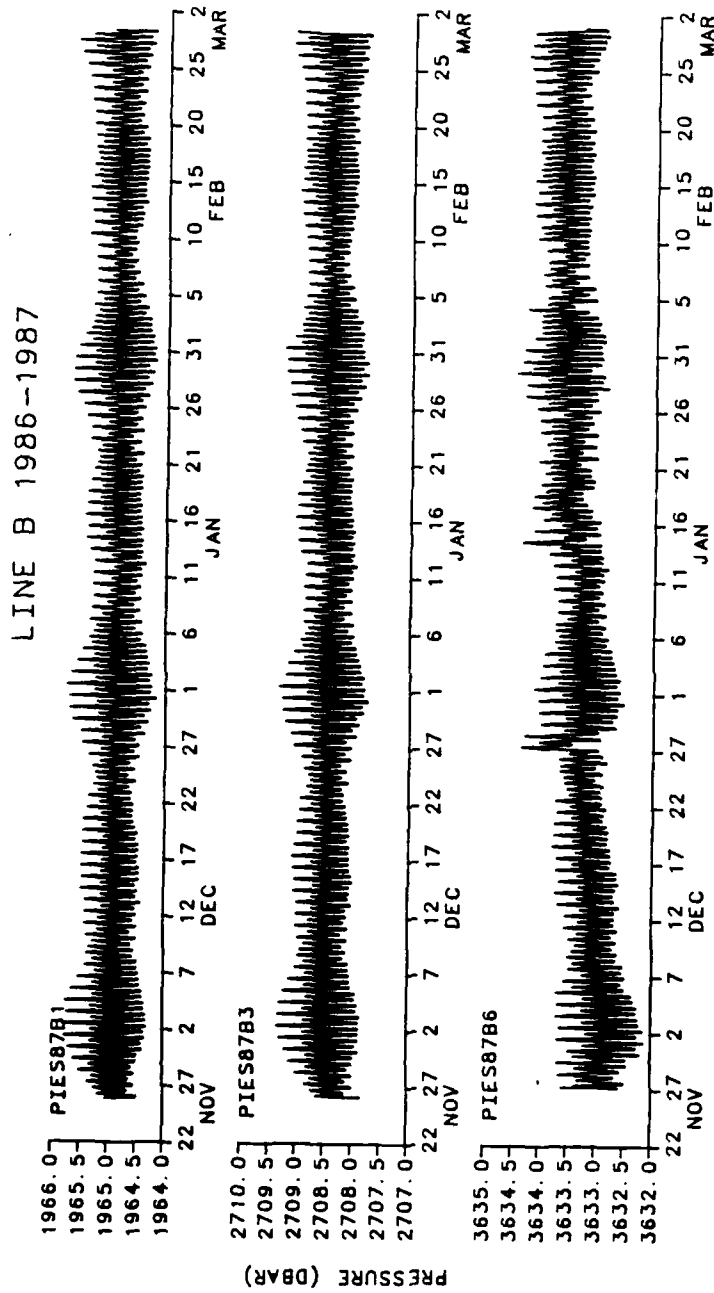


Figure 4: Half-hourly measured bottom pressure records for PIES87B1, PIES87B3 and PIES87B6. The start and end times, and records lengths are listed in Section 2.

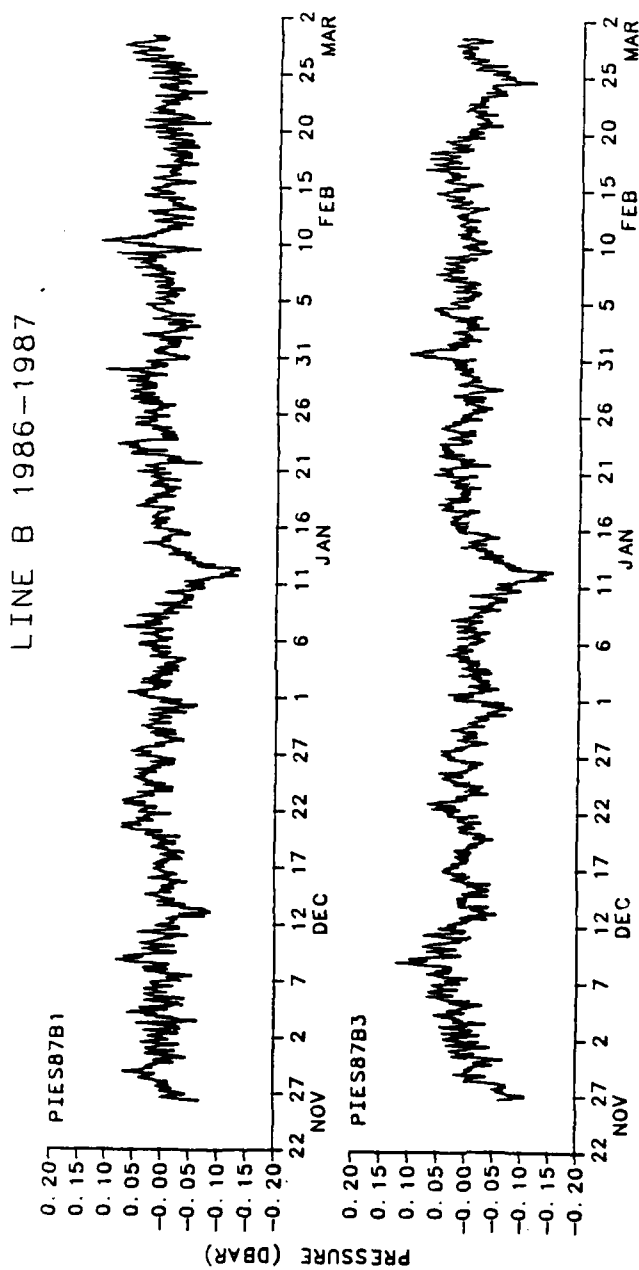


Figure 5: Half-hourly residual bottom pressure records for PIES87B1, PIES87B3. free parameters and tidal constituents are given in Section 2.

LINE B 1986 - 1987

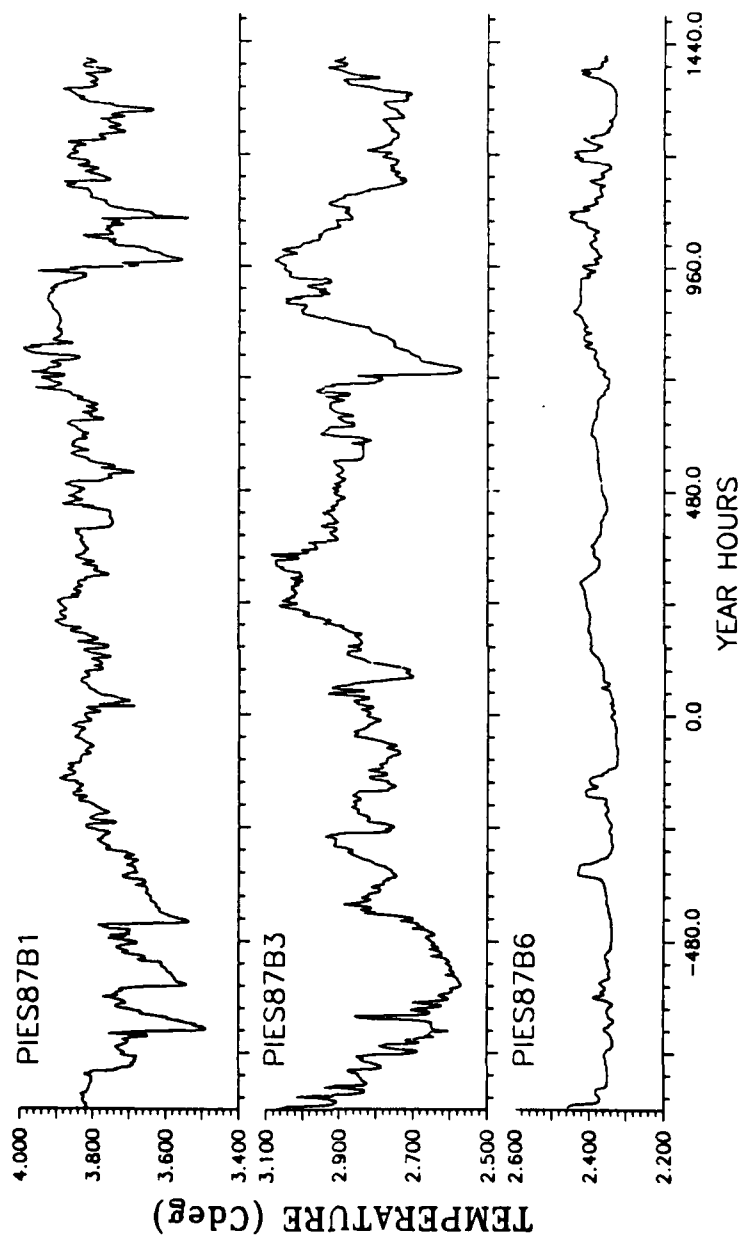


Figure 6: Half-hourly temperature records for PIES87B1, PIES87B3 and PIES87B6.

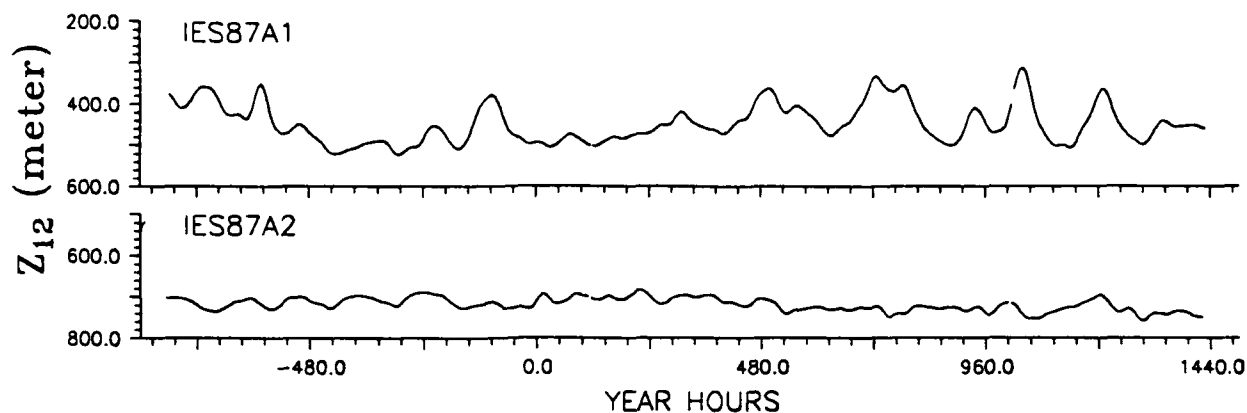
4 40 HRLP Data For Each Cross-Stream Line

The low-pass filtered thermocline depth (Z_{12}), bottom pressure and temperature records are plotted for each cross-stream line. The thermocline depth records for each cross-stream line are presented first. These are followed by the 40 HRLP residual pressure records and the 40 HRLP temperature data for the instruments which had these additional sensors.

The time scale is the same for all plots, with each increment corresponding to 10 days. The axis begins on 1200 GMT of the first date labelled.

Vertical scale for each variable is consistent between instruments. Each increment corresponds to 100 m for the Z_{12} records, to 0.05 dbar for the bottom pressure measurements, and to 0.1°C for the temperatures. The sampling intervals are 6 hours for all variables of the IESs and PIESs and 24 hours for those of the ATMs. The length and the start and end times of the data records are tabulated in Section 2.

LINE A 1986 - 1987



LINE C 1986 - 1987

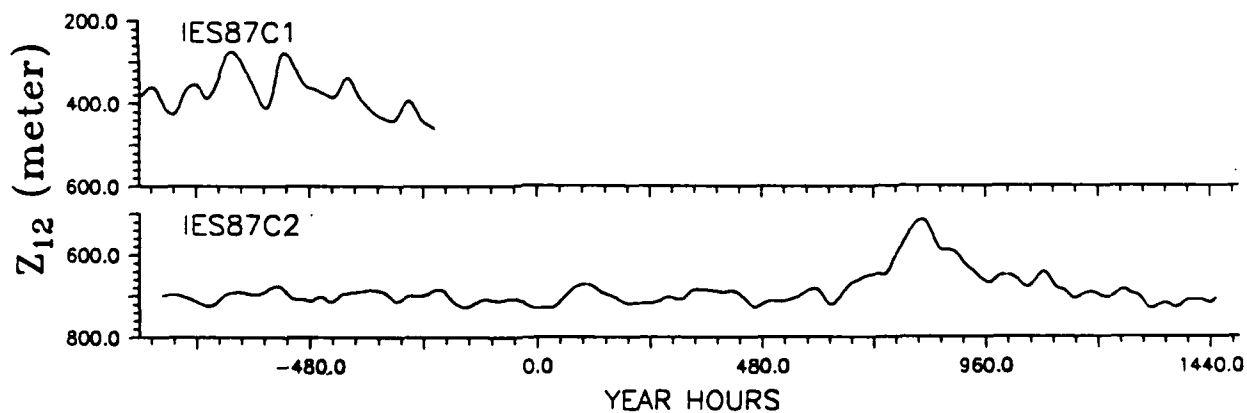


Figure 7.1: Thermocline depth records for Line A and C: records 40HR low-pass filtered at 6 hour intervals. For each instrument, the equation used to convert travel time to Z_{12} is given in Section 2.

LINE B 1986 - 1987

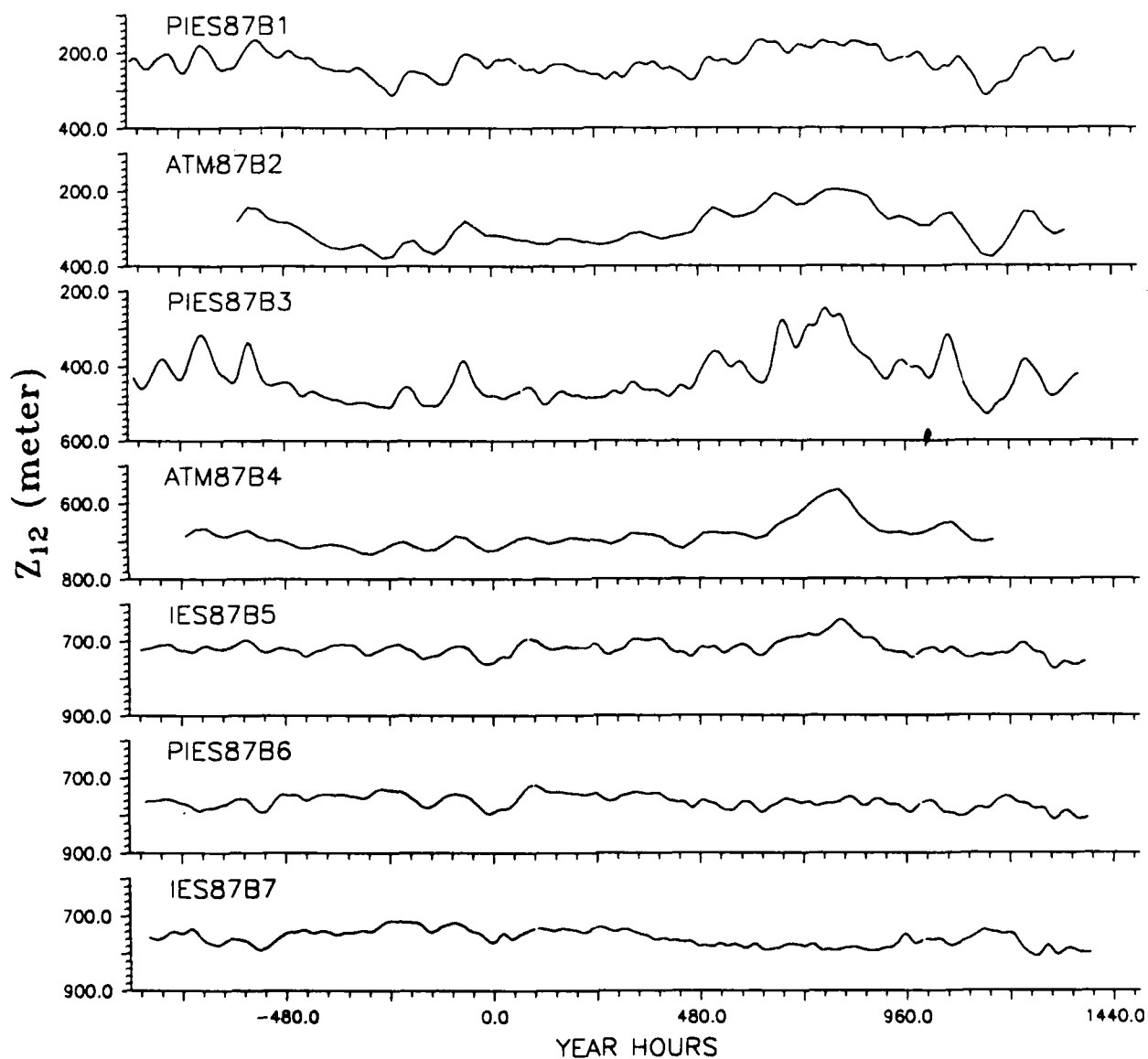


Figure 7.2: Thermocline depth records for Line B: (P)IESs records 40HR low-pass filtered at 6 hour intervals and ATM records 96HR low-pass filtered at 24 hour intervals.

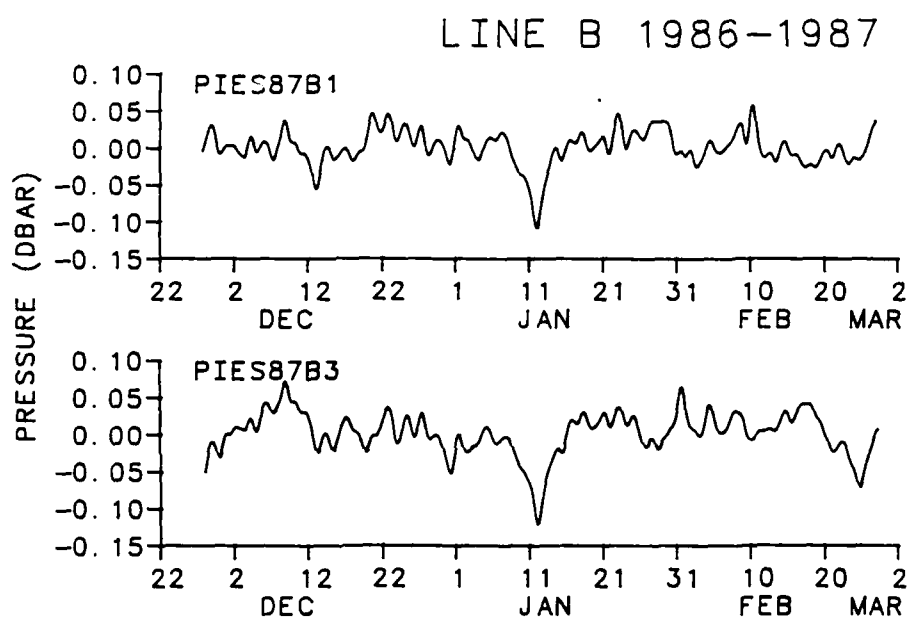


Figure 6 40HRLP bottom pressure records for PIES87B1 and PIES87B3 at 6 hour intervals.

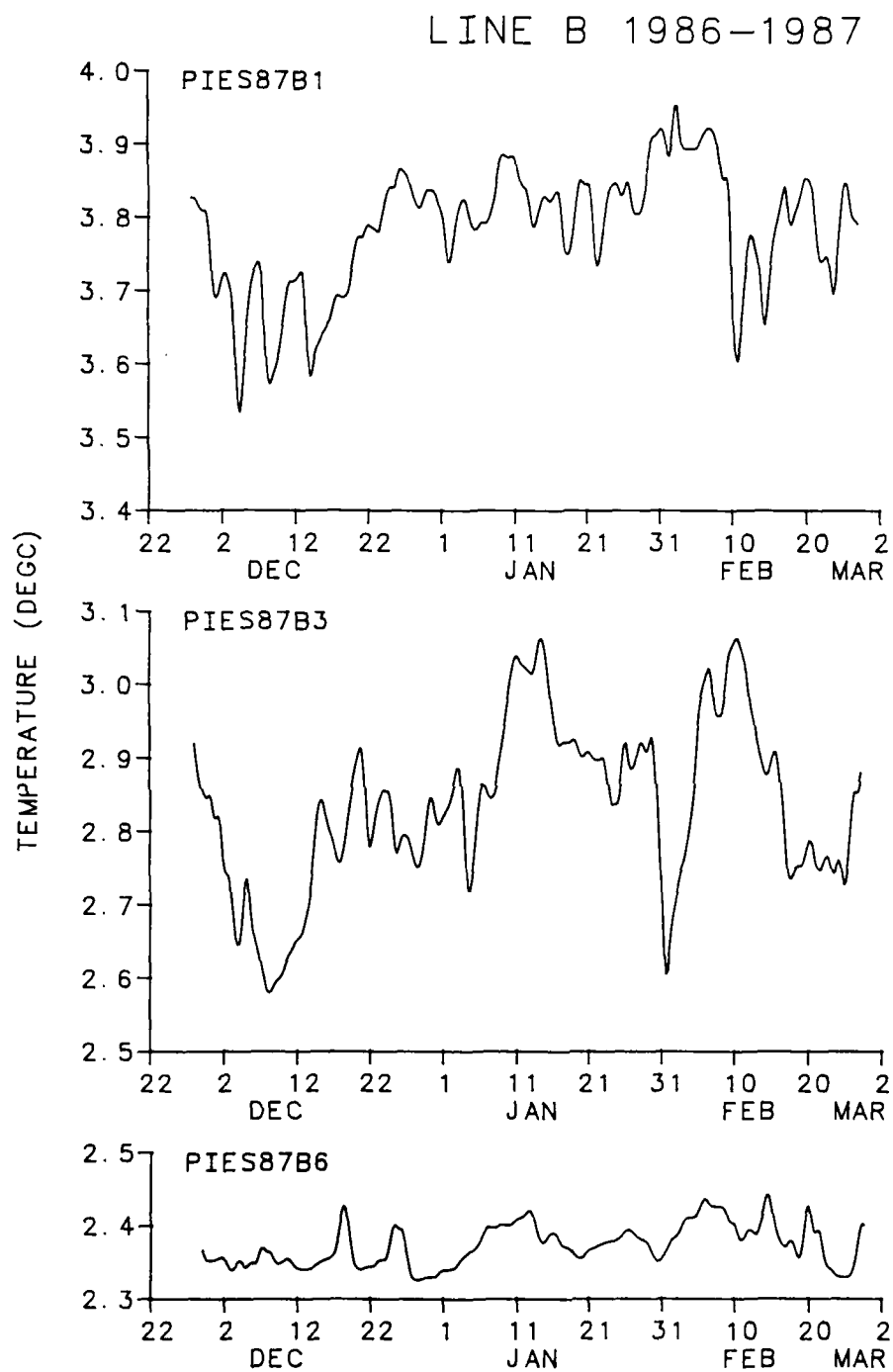


Figure 9: 40HRLP temperature records for PIES87B1, PIES87B3 and PIES87B6.
at 6 hour intervals.

5 Thermocline Depth Maps

Contour plots of the mean and variance fields and the error fields, the thermocline depth (Z_{12}) fields are presented.

Each of the contoured frames corresponds to the 160 Km by 140 Km boxed region shown in Figure 1. The axes, oriented 045°T , are referenced to a grid origin located at $35^\circ\text{N } 75^\circ\text{W}$. Each frame consists of a 9×8 square grid of points, at 20 Km spacing. The actual IES sites are indicated by the + marks and the positions are listed in Table 1.

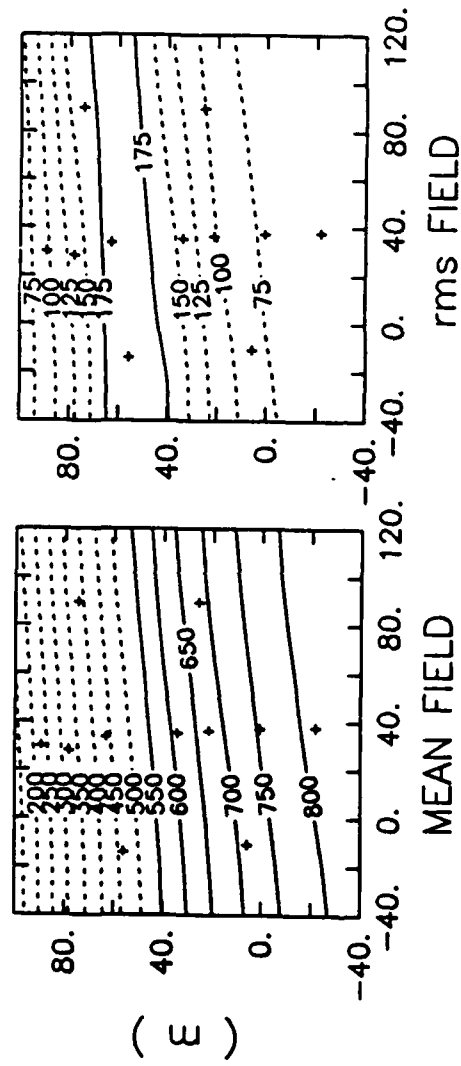


Figure 10: Mean field(left) for the 28 Nov. 1986 to 27 Feb. 1987 data and root-mean-square variance field(right) are contoured in plane view. Contour interval of the mean field is 50 m, with dashed lines indicating $Z_{12} \leq 500$ m. Contour interval of the variance field is 25 m with the dashed region corresponding to variance ≤ 150 m rms.

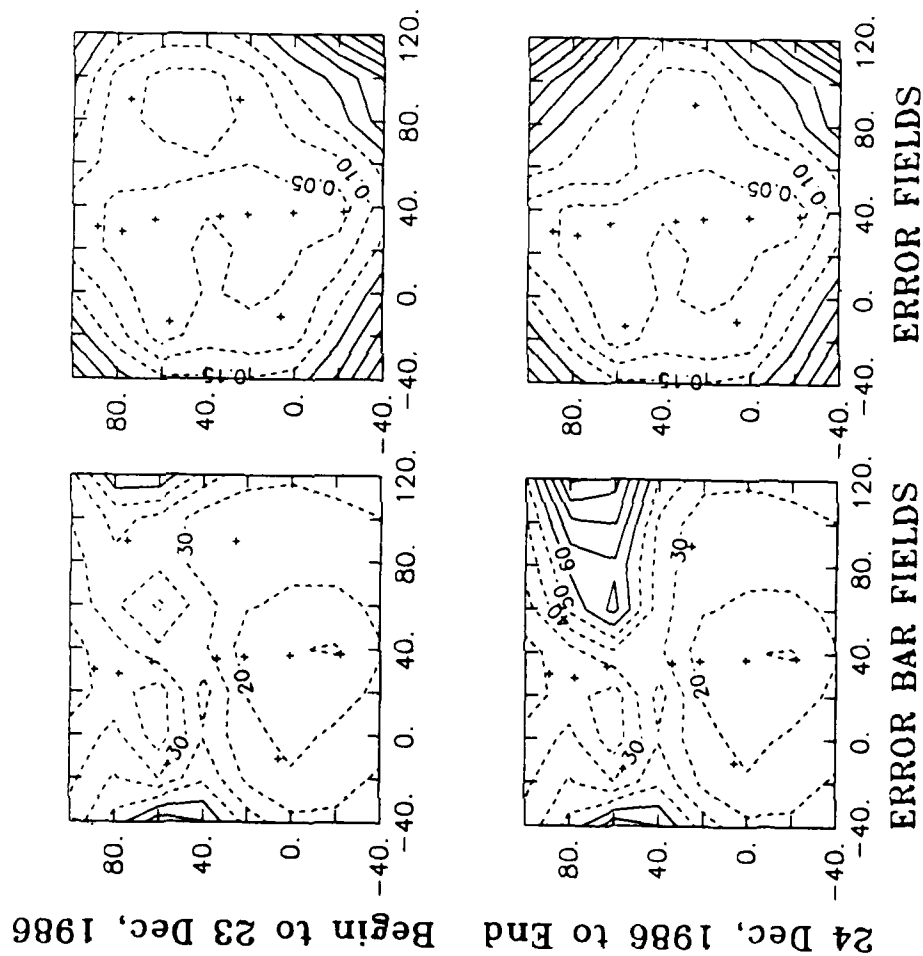
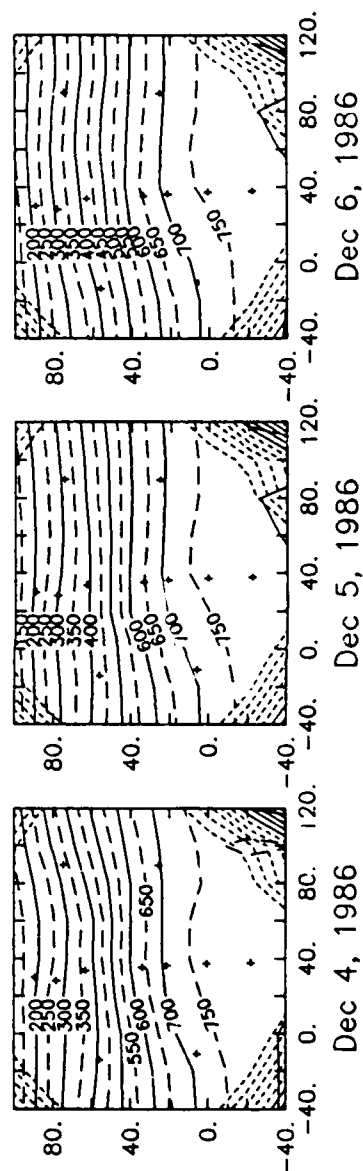
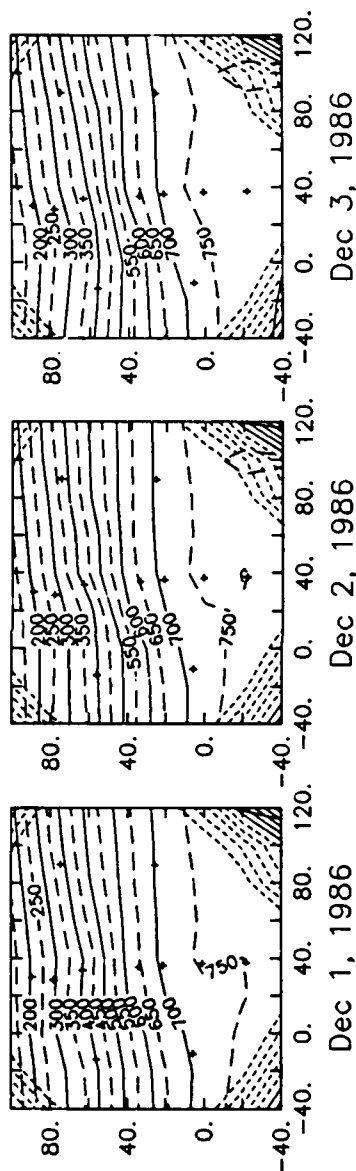
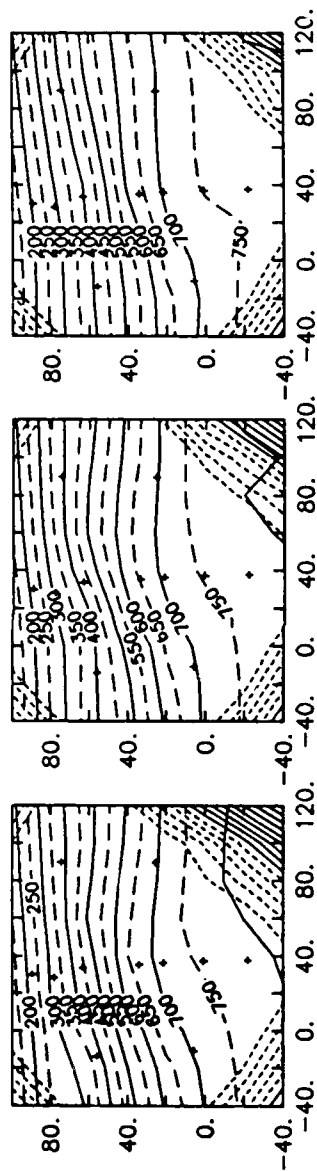
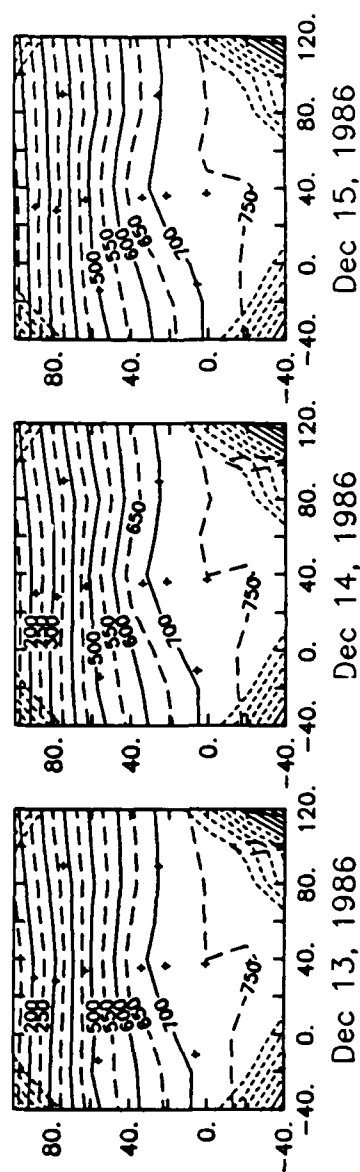
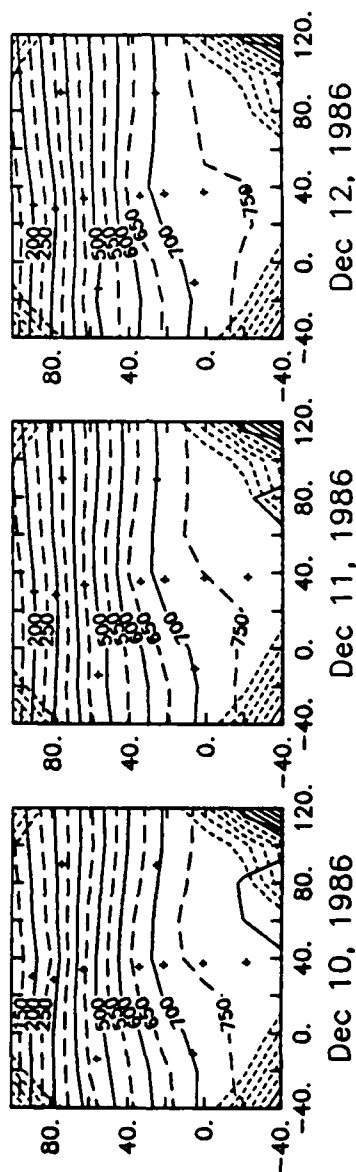
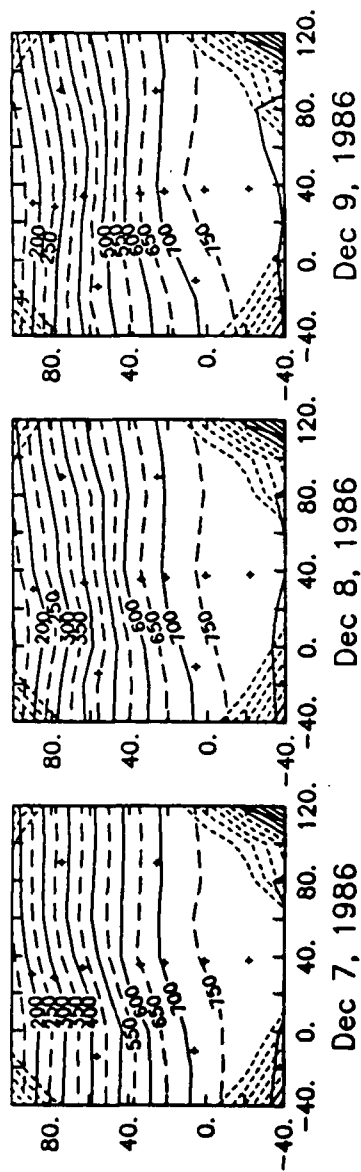


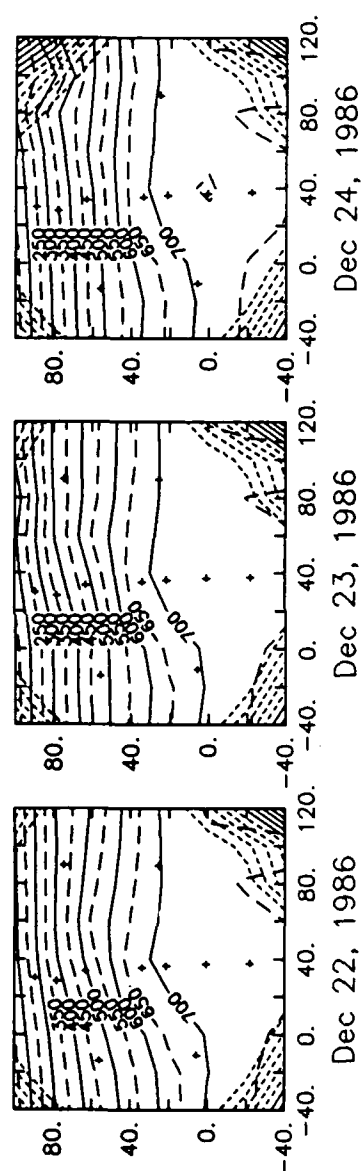
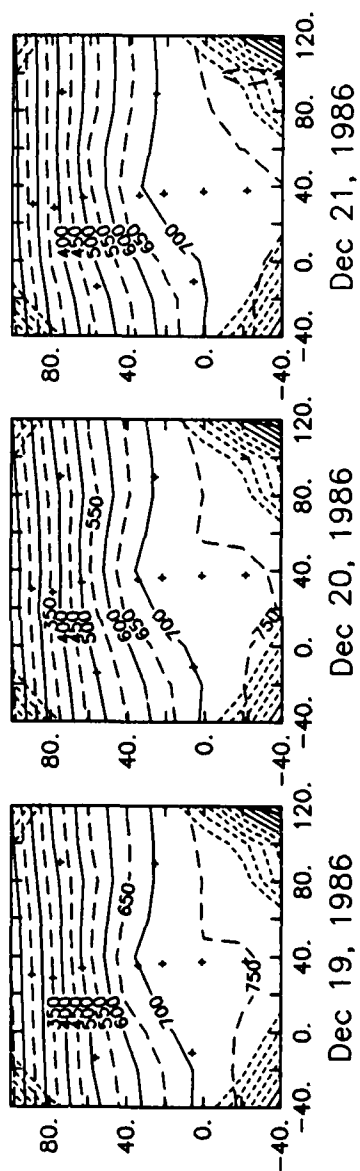
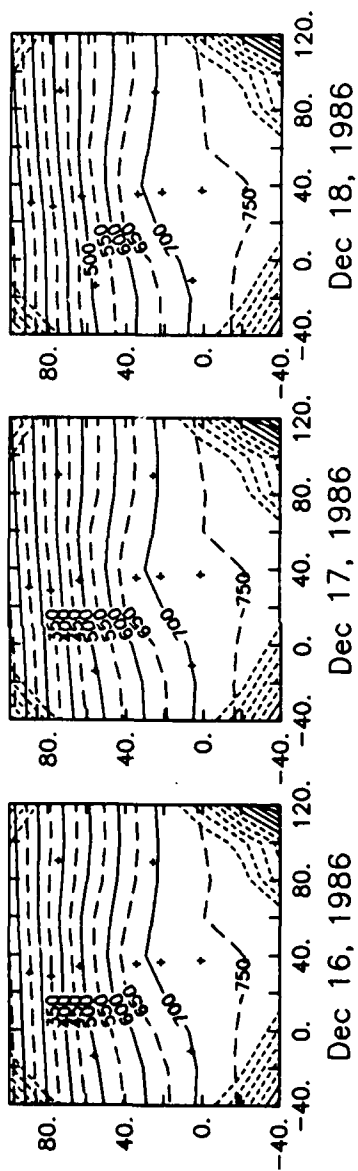
Figure 11: The error bar fields (left) have a contour interval of 10 m and the dashed region corresponds to errors < 50 m. The error (percent variance) fields, shown at right, are contoured at 5% intervals, with the dashed region corresponding to < 15% error. The error maps apply to the Z_{12} in Figure 12 for the dates shown.

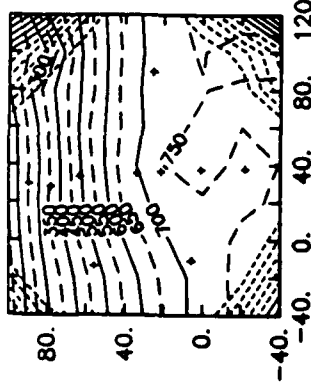
Figure 12:

The 12° isotherm depth, Z_{12} , field is shown at daily intervals from 28 Nov, 1986 to 27 Feb, 1987. The maps are shown for 1200 GMT on the date indicated at the bottom. The Z_{12} field is contoured by solid and dashed lines with 100 m intervals. The shorter dashed lines correspond the error maps are shown in Figure 11.

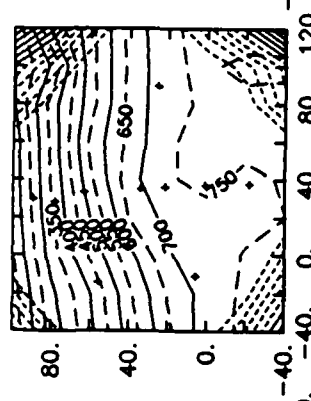




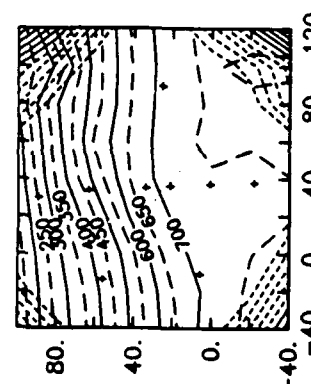




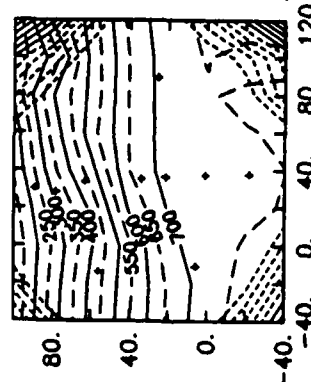
Dec 25, 1986



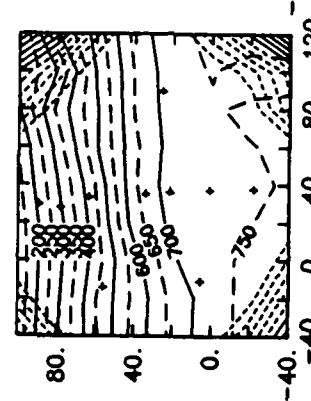
Dec 26, 1986



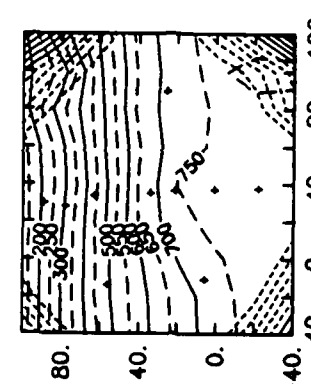
Dec 27, 1986



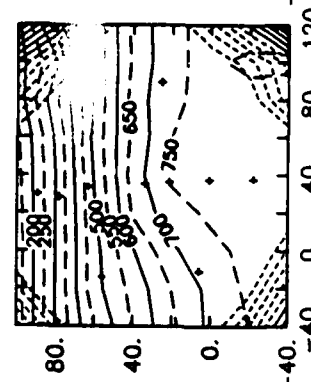
Dec 28, 1986



Dec 29, 1986



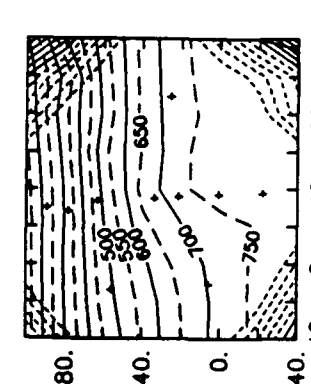
Dec 30, 1986



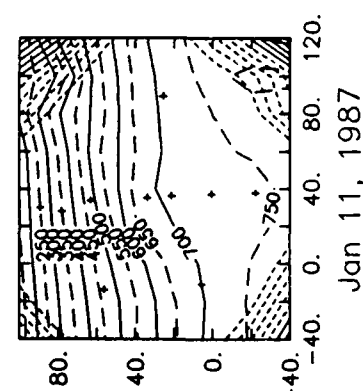
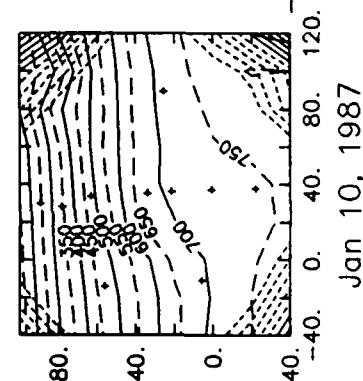
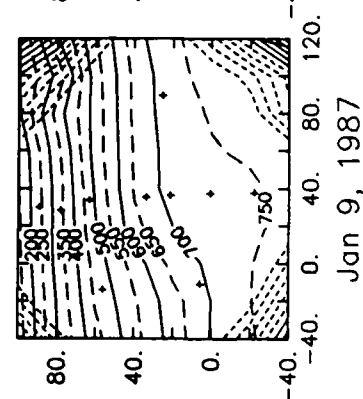
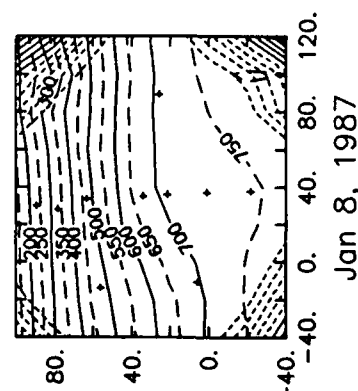
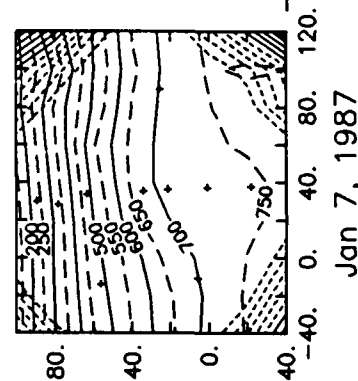
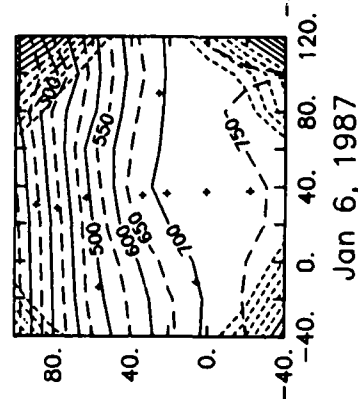
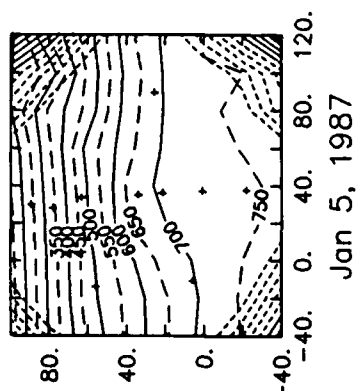
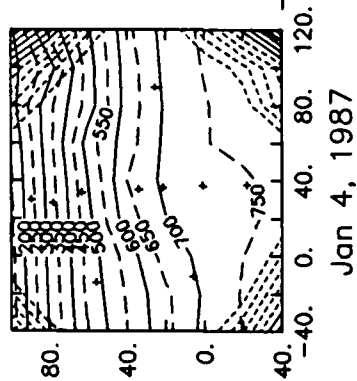
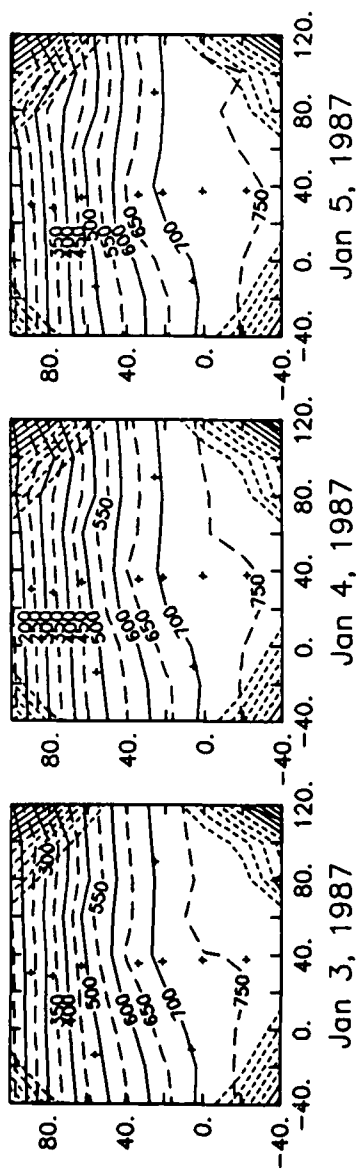
Dec 31, 1986

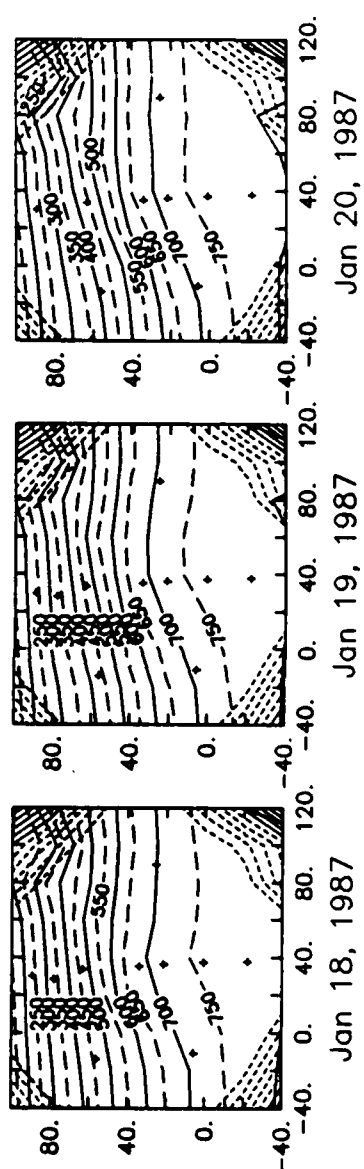
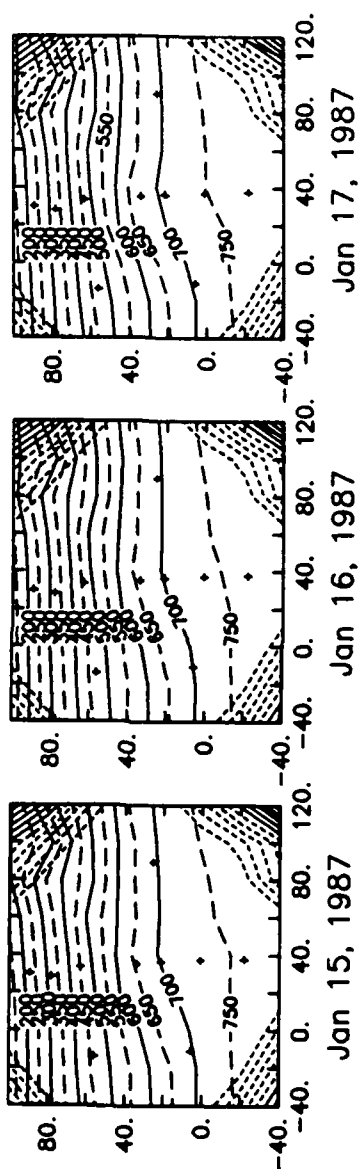
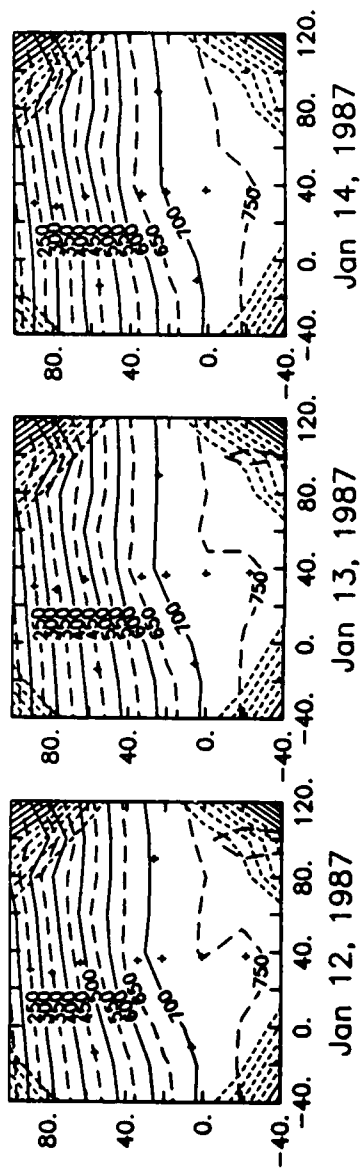


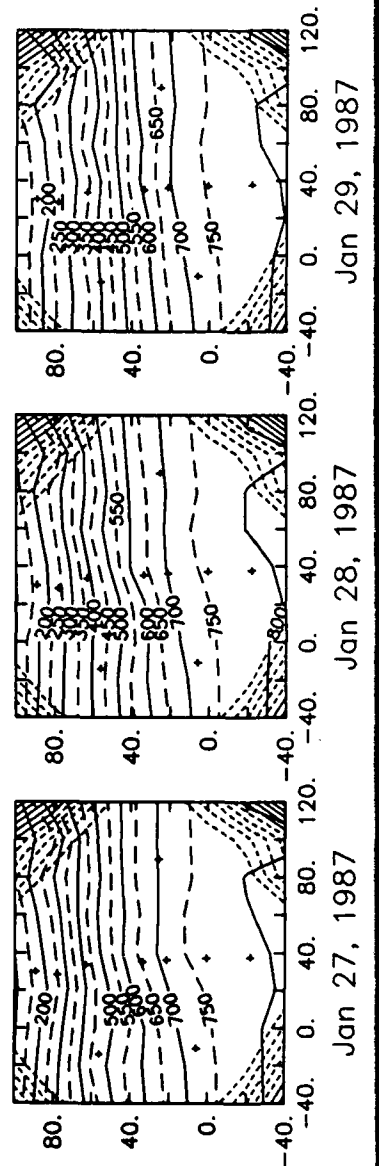
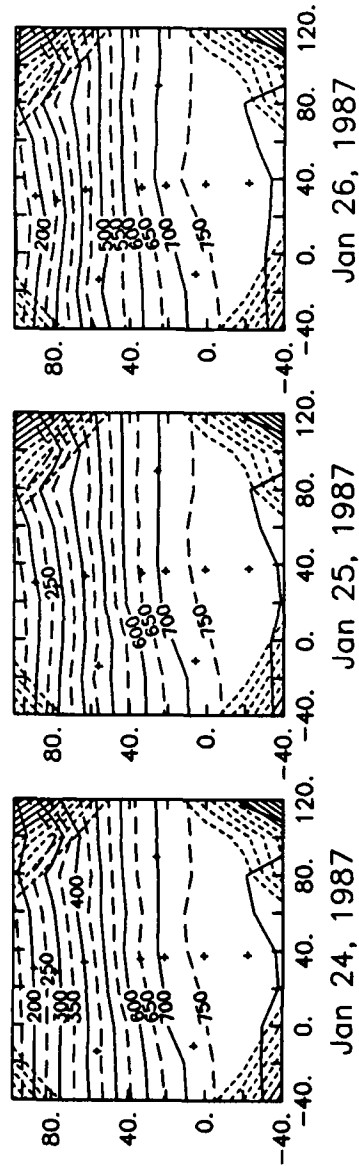
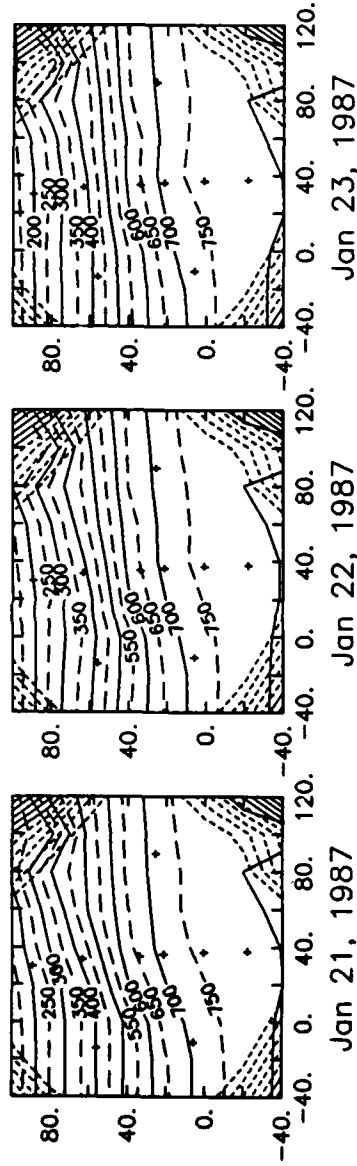
Jan 1, 1987

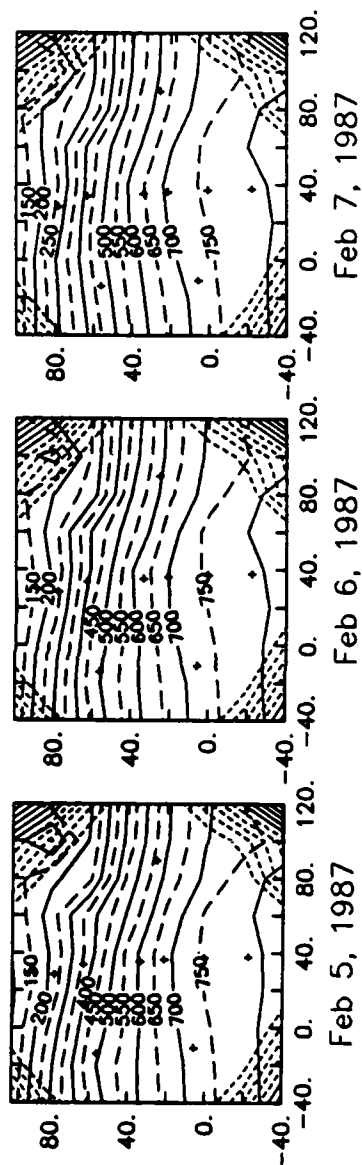
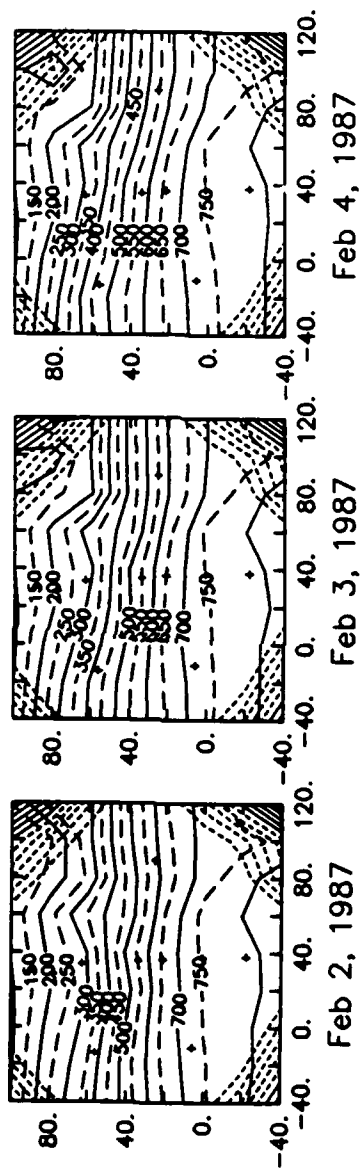
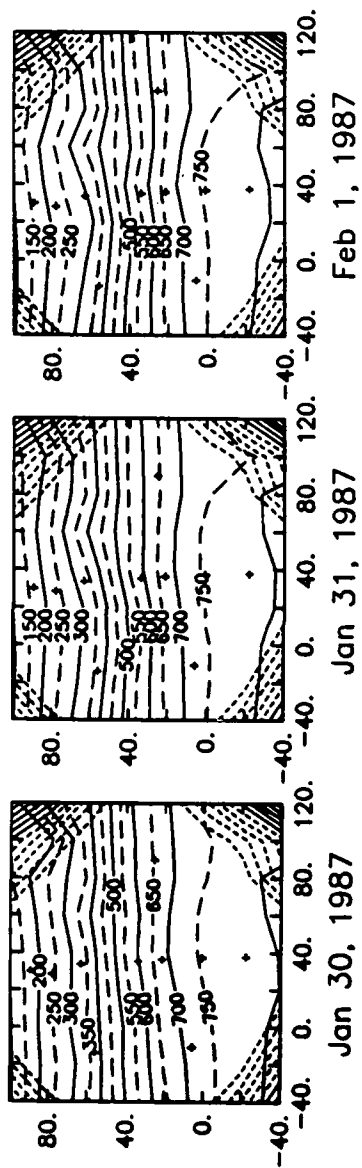


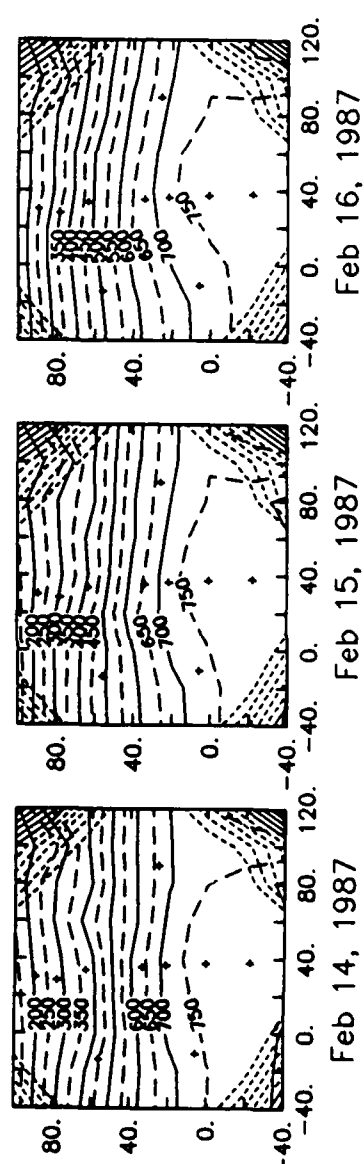
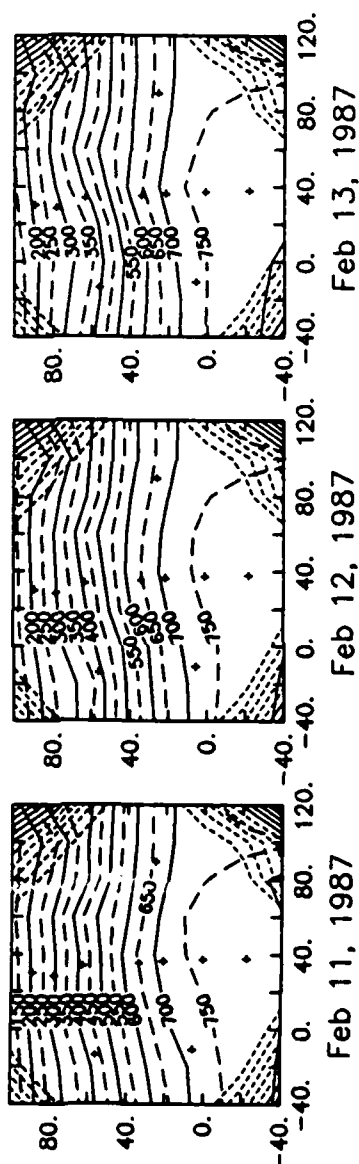
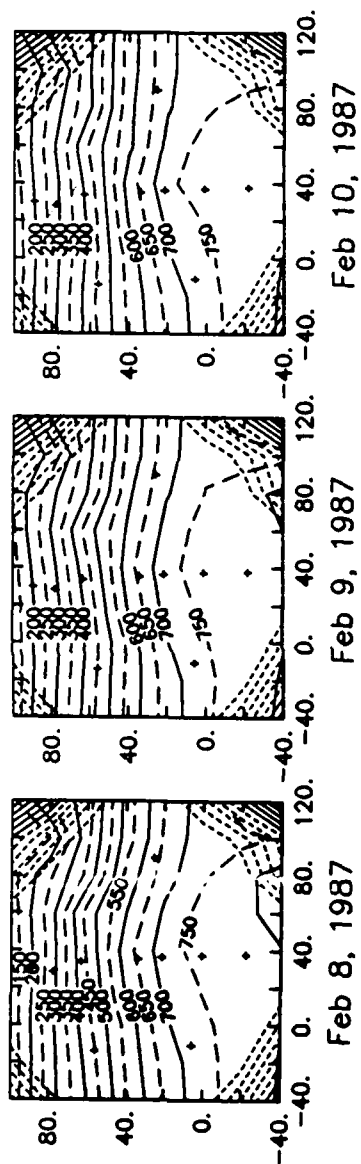
Jan 2, 1987

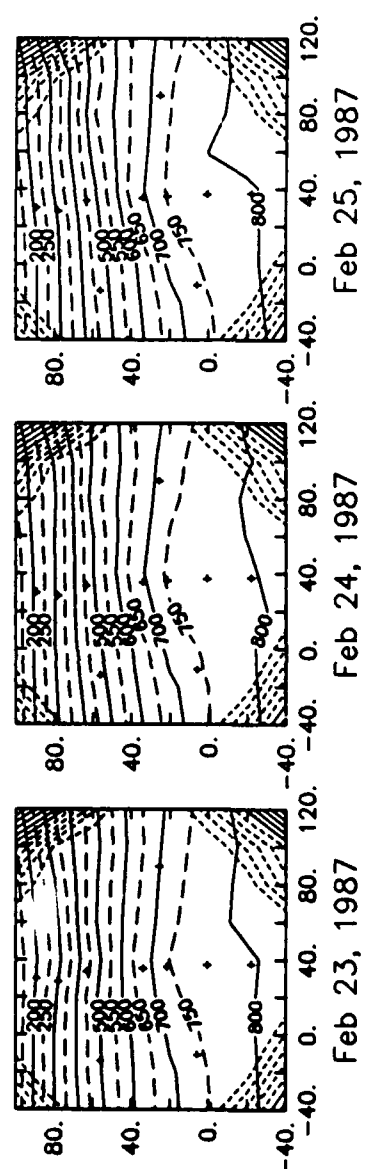
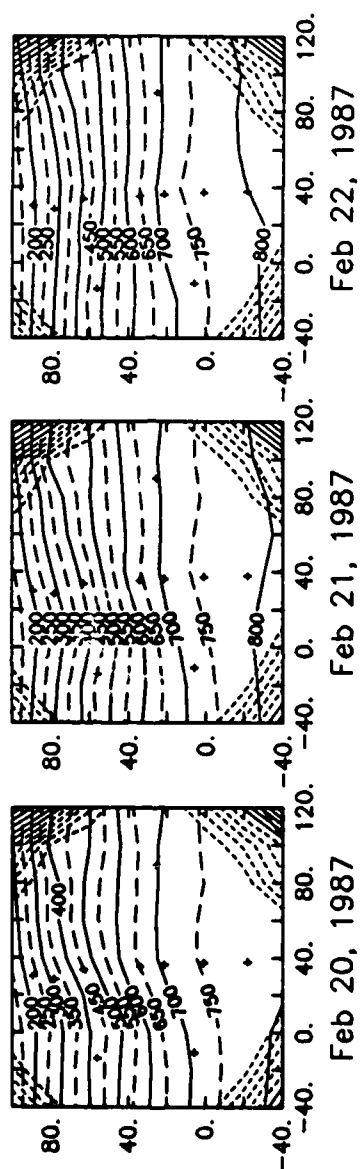
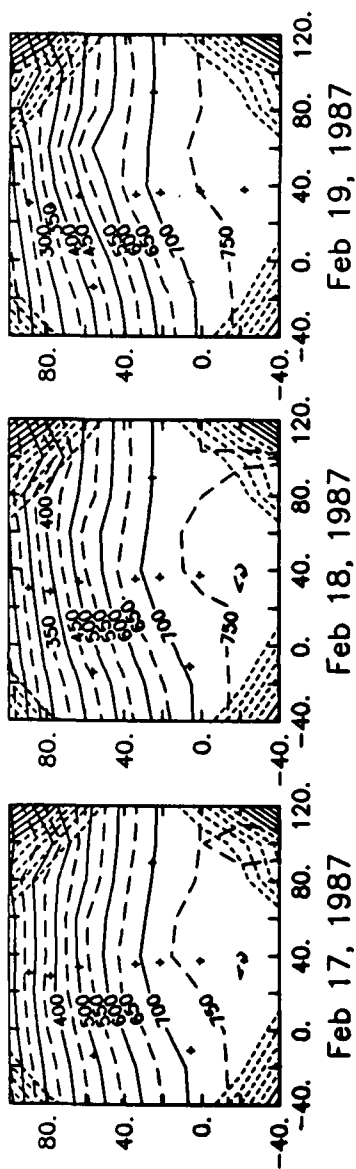


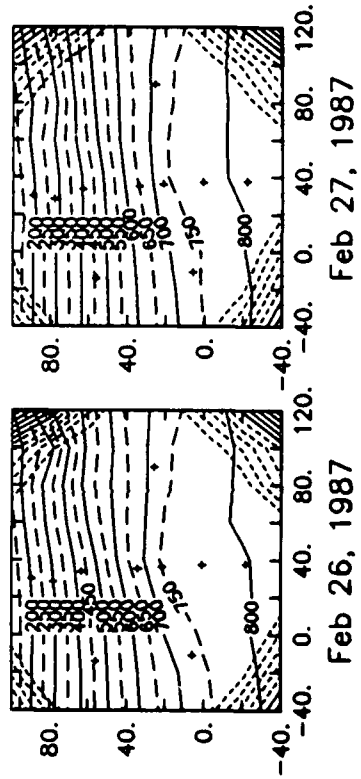












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REFERENCES

- Brooks, D. A. 1976. (Editor). Fast and Easy Time Series Analysis at NCSU. Technical Report. Center for Marine and Coastal Studies. North Carolina State University. Raleigh, NC.
- Carter, E. F. 1983. The statistics and dynamics of ocean eddies. Ph.D. Thesis. Harvard University.
- Chaplin, G. and D. R. Watts. 1984. Inverted echo sounder development. *Oceans '84 Conference Record. 1.* 249-253.
- Chaplin, G. and D. R. Watts. 1986. An acoustic ocean-transport meter. *IEEE Oceans '86 Proceeding*, Washington, D.C., Sept, 1986, 426-429
- Dixon, W. J. and M. B. Brown. 1979. (Editor). *BMDP - 79 Biomedical Computer Programs P-series*. University of California Press. Berkeley, CA. 880 pp
- Munk, W. H. and D. E. Cartwright. 1977. Tidal spectroscopy and prediction. *Philos. Trans. R. Soc. London*, 259, 533-581.
- Rossby, T. 1969. On monitoring depth variations of the main thermocline acoustically. *J. Geophys. Res.* 74. 5542-5546.
- Tracey, K. L. and D. R. Watts. 1988. Inverted echo sounder processing procedures. University of Rhode Island. GSO Technical Report (in preparation).
- Tracey, K. L., Friedlander, A. I. and D. R. WATTS. 1987. Objective analysis of the Gulf Stream thermal front: method and accuracy. GSO technical Report 87-2.
- Watts, D. R. and W. E. Johns. 1982. Gulf Stream meanders: observations on propagation and growth. *J. Geophys. Res.* 87. 9467-9476.
- Watts, D. R. and H. Kontoyiannis. 1986. Deep-ocean bottom pressure and temperature sensors report: methods and data. University of Rhode Island. GSO Technical Report 86-8. 111 pp.
- Watts, D. R. and H. T. Rossby. 1977. Measuring dynamic heights with inverted echo sounders: Results from MODE. *J. Phys. Oceanogr.* 7. 345-358.

- Watts, D. R., K. L. Tracey and A. I. Friedlander. 1988. Processing accurate maps of the Gulf Stream thermal front using objective analysis. *J. Geophys. Res.* (submitted)
- Watts, D. R. and M. Wimbush. 1981. Sea surface height and thermocline depth variations measured from the sea floor. *International Symposium on Acoustic Remote Sensing of the Atmosphere and Oceans, Proceedings*, Calgary, Alberta, Canada.

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